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DEVELOPMENT AND PRELIMINARY DESIGN OF A SORBENT-OIL RECOVERY SYSTEM

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Hydronautics, Incorporated
Laurel, Maryland

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Development and Preliminary Design of a Sorbent-Oil Recovery System

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27 Abstract

A development program was completed and preliminary designs were prepared for 3000 gallon/hour protected water and 10,000 gallon/hour unprotected water Sorbent Oil Recovery Systems. The five phases in the development program were: (1) characterization of the sorbent material, (2) the development of the sorbent broadcasting system, (3) the development of the harvesting conveyor and evaluation of overall recovery performance, (4) the development of the sorbent regeneration system and (5) model tests of a 1/4-scale model recovery platform. The development program showed that a continuous sorbent-oil recovery system is feasible using 30 or 80 PPI polyurethane sorbent chips. In one pass about 90 percent of the oil in a 1.5 mm slick can be recovered. The water content of the Recovered Fluid is less than 10 percent. The preliminary designs are presented with detailed descriptions of the system components, operating procedures, and costs. (EPA)
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DEVELOPMENT AND PRELIMINARY DESIGN OF A SORBENT-OIL RECOVERY SYSTEM

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Contract No. 68-01-0066
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A development program was completed and preliminary designs were prepared for 3000 gallon/hour protected water and 10,000 gallon/hour unprotected water Sorbent Oil Recovery Systems. The five phases in the development program were: (1) the characterization of the sorbent material, (2) the development of the sorbent broadcasting system, (3) the development of the harvesting conveyor and evaluation of overall recovery performance, (4) the development of the sorbent regeneration system and (5) model tests of a 1/4-scale model recovery platform. The development program showed that a continuous sorbent-oil recovery system is feasible using 30 or 80 PPI polyurethane sorbent chips. In one pass about 90 percent of the oil in a 1.5 mm slick can be recovered. The water content of the recovered fluid is less than 10 percent. The preliminary designs are presented with detailed descriptions of the system components, operating procedures, and costs.

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SECTION I

CONCLUSIONS

1. Continuous sorbent oil recovery systems are practical and can be designed to recover a wide range of oil products.

2. Systems designed for recovery rates of 3000 GPH in protected waters and 10,000 GPH in unprotected waters will basically satisfy the general and specific design goals given by the EPA.

3. Sorbent oil recovery systems can recover about 90 percent of the oil from a slick in a single pass. This performance can be achieved over a wide range oil viscosities, slick thickness and wave heights.

4. Water in the recovered fluid will be about 10 percent for typical operating conditions.

5. Depending on the options selected and the number produced, the initial cost of a 3000 GPH protected water recovery system will range between $40,000 and $80,000. For a 10,000 GPH unprotected water recovery system the cost will range between $55,000. and $105,000. Operating costs for the 3000 GPH system will be between $100/hour and $200/hour and for the 10,000 GPH system between $400/hour and $600/hour.

6. Based on the results of the development program, rational design procedures have been formulated for the selection of system and sub-system characteristics and hardware.

7. The sorbent material used in the recovery system should be open cell reticulated polyurethane foam cut into chips approximately 3 in. × 3 in. × 1/4 in. 80 PPI foam should be used for oils with viscosities less than 1000 cps and 30 PPI foam should be used for viscosities greater than 1000 cps.

8. A pneumatic sorbent broadcasting system using a fan with a long shavings type wheel and a moving parallel plate distribution nozzle will provide satisfactory sorbent distribution patterns and conveying performance.

9. The recovery platform must provide a sheltered location for sorbent broadcasting to reduce losses in winds. If this is done the sorbent lost rate will be small under normal operating conditions and will not exceed 2 percent of the broadcast rate in winds of 30 mph.

10. The recovery platform should have a catamaran configuration because it provides a sheltered location for broadcasting the sorbent, a means of herding the sorbent to the harvesting conveyor and a location for mounting the harvesting conveyor.

11. In order to achieve high recovery efficiency the sorbent material should remain in contact with the slick for periods of 15 to 30 seconds.

12. The harvesting conveyor should be at an angle of 45 degrees and run with a linear belt speed equal to the sweep speed.

13. A converging belt type sorbent regenerator can regenerate sorbent material at a loading of .30 ft^3/ft^2 and a belt speed of 1.0 ft/sec. A squeezing force of about 200 lb/in. of belt width is required. The density of the regenerated sorbent after squeezing will be about 6.0 lb/ft^3 which is satisfactory for pneumatic broadcasting.

14. The sorbent material can be regenerated with oil viscosities up to 20,000 cps at the time of squeezing. Heating coils will be required to reduce the oil viscosity to about 1000 cps for satisfactory flow in the oil collection pans.

15. The sorbent material can be regenerated in excess of 100 times without deterioration.

16. Model tests conducted at 1/4 full scale for the 10,000 GPH system demonstrated that a continuous, stable, sorbent broadcasting and recovery cycle is possible and that it is not sensitive to waves and sweep speed.

SECTION II

RECOMMENDATIONS

The development program and design studies carried out in this project indicate that a continuous sorbent oil recovery system is feasible and practical. In order to advance such systems to field applications it is necessary to design, build and test a prototype system. It is recommended that such a prototype program be undertaken. Because of its more general application and lower cost, the 3000 GPH protected water unit would be a suitable candidate for such a program.

SECTION III

INTRODUCTION

In the event of an oil spill it is desirable from the standpoint of the total environment to physically remove the oil from the water. There are several basic methods which can be employed for physical removal of the oil. These are: direct skimming by means of a special skimming device; the use of pumps in conjunction with oil-water separation equipment; or oil collection with a sorbent material followed by mechanical removal of the sorbent material. The sorbent-material method has the advantages that the sorption process is not affected by waves or current and that a high percentage of oil in the recovered fluid can be obtained. As a result, large volumes of sorbent material have been used in oil spill clean up operations. However, this method has disadvantages such as the generation of a large volume of waste material which requires controlled disposal and the lack of mechanical systems to recover the sorbent material. Thus, the use of sorbent materials for oil recovery has been an effective but expensive procedure.

In an effort to overcome the disadvantages associated with the use of sorbent material, the U. S. Environmental Protection Agency issued a RFP for the development of Sorbent Oil Recovery Systems in late 1970. HYDRONAUTICS, Incorporated was awarded one of five research contracts in June of 1971 for the development of a sorbent oil recovery system based on the use of a synthetic foam sorbent material which could be recycled many times. This report presents the results of this development effort.

In order to guide the developmental phase, the Environmental Protection Agency provided the following general design goals for an oil recovery system using sorbent materials.

GENERAL DESIGN GOALS

1. Rapid oil recovery rate.

2. Complete removal of oil from the water surface.

3. Minimum amounts of water entering each unit process.

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4. Minimum influence of water motion and waves on collection efficiency.

5. Minimum amount of auxiliary equipment.

6. Reject floating solids of a size which will interfere with the efficiency of, or damage, the recovery system.

7. High mobility and maneuverability.

8. Compatibility with marine life.

9. Reasonable first cost.

10. Low operating expense.

11. Minimum maintenance requirements.

12. Maximum ease and speed of repairs.

13. Readily available replacement parts.

14. System independent of physical properties of oil.

15. Readily available sorption material.

16. Sorption material easily transportable to location of spill.

17. Sorption material must be compatible with land harvest methods.

18. Sorption material must not increase flammability of oil.

In addition, specific design goals were provided for a protected water system capable of recovering 3000 gallons/hour from a 1.5 mm thick slick and an unprotected water system capable of recovering 10,000 gallons/hour from a 1.5 mm slick. These specific design goals are outlined in the subsequent sections of this report along with preliminary designs for these two systems.

In the development of a sorbent oil recovery system it is desirable to consider the basic unit operations involved. These basic unit operations are:

1. Sorbent Broadcasting
2. Oil-Sorbent Harvesting
3. Oil-Sorbent Separation
4. Vessel or Platform Configuration
5. Oil Storage or Disposal
6. Sorbent Reuse or Disposal

Based on these unit operations, a development program was formulated and carried out which included five experimental tasks and a preliminary design task. The five experimental tasks were:

1. Characterization of the Sorbent Material
2. Development of the Sorbent Broadcasting System
3. Development of the Harvesting Conveyor and Evaluation of Overall Oil Recovery Performance
4. Development of the Oil Sorbent Separation System, and
5. Model tests of a 1/4-scale Recovery Platform to determine system stability and operation in waves.

The preliminary design task included the formulation of design procedures and criteria based on the five experimental tasks and the preparation of preliminary designs for the 3000 and 10,000 gallon/hour recovery systems.

The complete results of the sorbent oil recovery system development program are presented in this report. Section IV presents a brief description of each of the five experimental tasks in the development program; the details and the data from each of these tasks are presented in the appendices. Section V presents a summary of the design methods, criteria and observations which resulted from the development program. Sections VI and VII present descriptions and technical details from the preliminary designs of the 3000 and 10,000 gallons per hour recovery systems, respectively.

SECTION IV

DEVELOPMENT PROGRAM

Five experimental tasks were carried out in support of the development of an Oil-Sorbent Recovery System. These five tasks are briefly described in this section and additional details are presented in the appendices.

CHARACTERIZATION OF THE SORBENT MATERIAL

The objective of this task was to develop data on the oil absorption capabilities of the sorbent material as a function of sorbent characteristics, oil characteristics, slick thickness and residence time on the slick. The sorbent material selected for use in the oil-sorbent recovery system was an open-cell reticulated polyurethane foam made by the Scott Paper Company. This material was selected during the proposal stage of this project and was based on previous work carried out by HYDRONAUTICS, Incorporated using sorbent materials. This work is reported in Reference 1.

The experiments were carried out in a 4 ft by 4 ft plastic tank 10 in. deep. This tank was equipped with a temperature control system, temperature measuring devices, and a micrometer for measuring oil slick thickness. Tests were conducted by establishing a slick of known characteristics and thickness on the water surface. A chip of sorbent material of known weight was dropped on the slick and allowed to sit for a given time. The chip was then picked up, allowed to drain for 10 seconds and reweighed to determine the amount of oil picked up. This process was carried out with several chips and an average value was taken for the amount of oil absorbed. The range of parameters covered in the tests are given in Table 1.

In a system in which the sorbent material is reused, the important thing is not to maximize the quantity of oil absorbed per unit volume of sorbent, but rather to maximize the total rate of oil absorption. As a result, a high percentage of the slick surface must be covered with sorbent material and individual sorbent chips will not have the opportunity to absorb oil to their maximum capacity. Thus, it is most meaningful to express the oil absorption performance of the sorbent as an absorption ratio rather than as either the

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absolute volume of oil absorbed or the maximum volume of oil that could be absorbed. The absorption ratio is defined as the ratio of the amount of oil absorbed to the amount of oil directly beneath the sorbent chip. This ratio indicates the extent to which oil in the slick can flow in the edges of the chip and the inverse of this ratio indicates the percentage of the slick which must be covered with sorbent for complete oil recovery.

TABLE 1

Range of Parameters in Sorbent Material Characterization Tests

Parameter	Range
Slick Thickness	0.5 - 3.5 mm
Oil Type	Diesel, No. 4, Crude, Bunker "C"
Slick Temperature	4 - 27°C
Residence Time of Sorbent on Slick	0 - 60 sec. Mostly 5, 10, 15, 30 sec.
Sorbent Porosity	30,60,80,100, Mostly 30 and 80 PPI
Sorbent Chip Geometry	Square and Rectangular
Sorbent Reusability	Fresh and Regenerated, Mostly Regenerated

Most of the tests were carried out using 3 in. × 3 in. × 3/8 in. chips of the sorbent material. Tests with rectangular chips did not show significant improvements in the absorption ratio. It was believed that rectangular chips might be more difficult to broadcast so they were not considered further. Typical test results are presented in Figures 1 and 2 which show the effects of oil viscosity and residence time on the absorption ratio. Both figures apply to slick thicknesses of 1 to 2 mm. Figure 1 is for 30 PPI (pores per linear inch) and Figure 2 is for 80 PPI polyurethane foam. The test results for other conditions as well as a more detailed description of this task are presented in Appendix A.

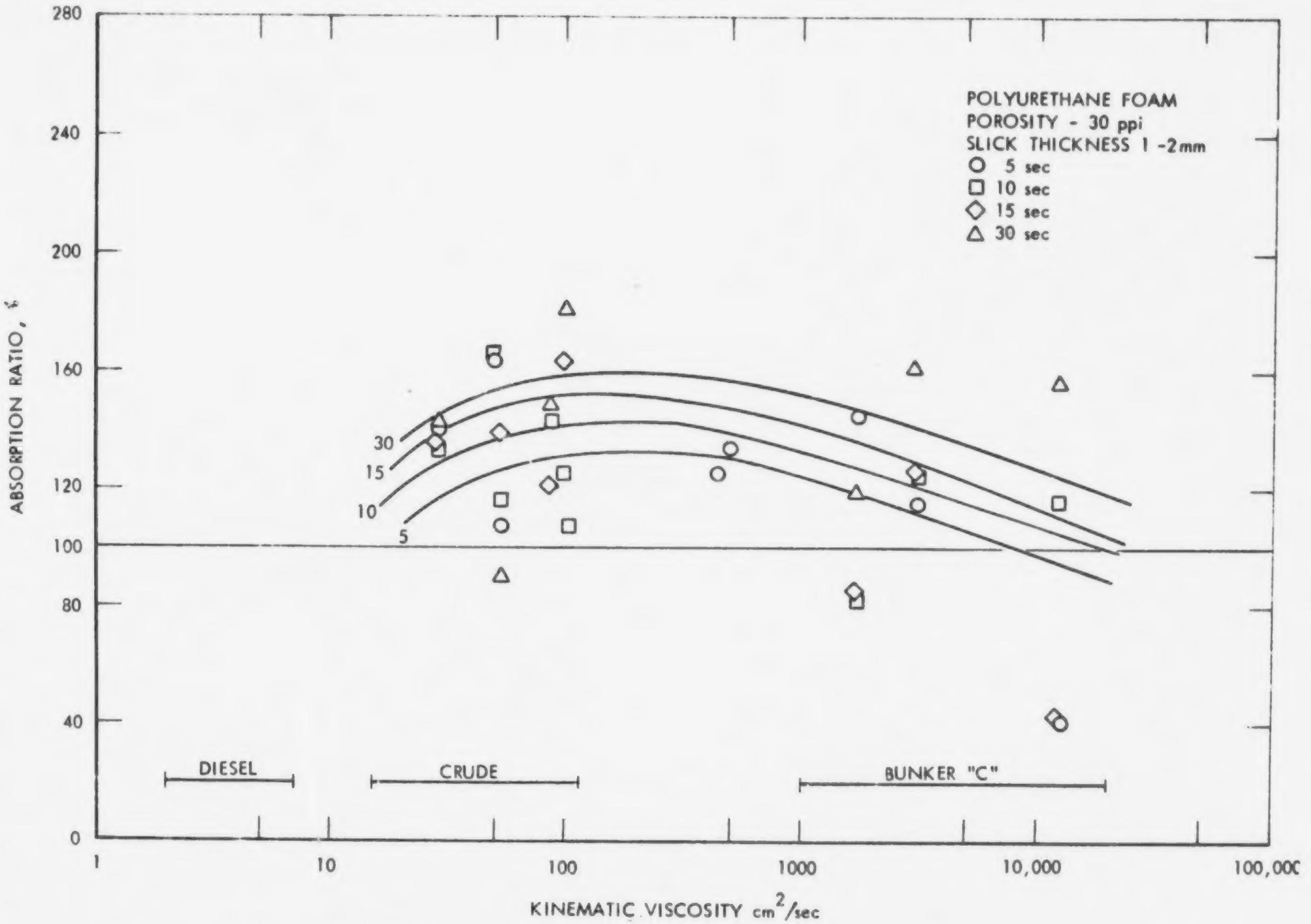


FIGURE 1 - EFFECT OF VISCOSITY AND RESIDENCE TIME ON OIL ABSORPTION FOR 30 PPI POLYURETHANE FOAM

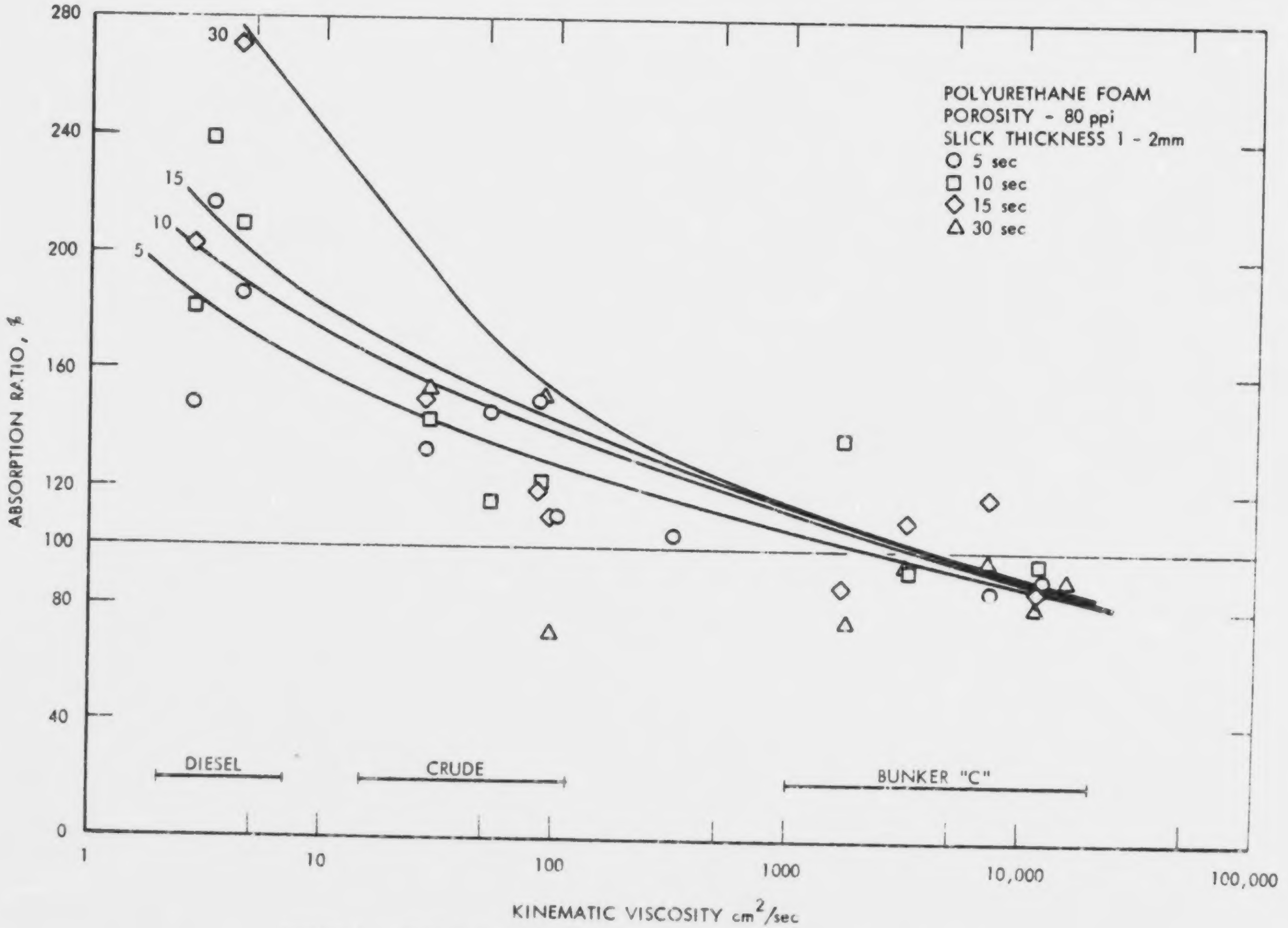


FIGURE 2 - EFFECT OF VISCOSITY AND RESIDENCE TIME ON OIL ABSORPTION FOR 80 PPI POLYURETHANE FOAM

The important results from this development task can be summarized as follows:

- The absorption ratio decreases with increasing oil viscosity. For oils such as No. 6 and Bunker "C" almost 100 percent coverage of the slick will be required.

- The absorption ratio does not increase greatly with residence time for viscous oils such as No. 6 and Bunker "C".

- 30 and 80 PPI foam have equal absorption ratios for oils with viscosities greater than 50 cps. For lower viscosities, the 80 PPI foam is superior because oil will not drain out of it as it is removed from the slick. Tests were not conducted with viscosities less than 2 cps.

- Square chips have as high absorption ratios as rectangular chips for the range of slick thickness and oil viscosities of interest.

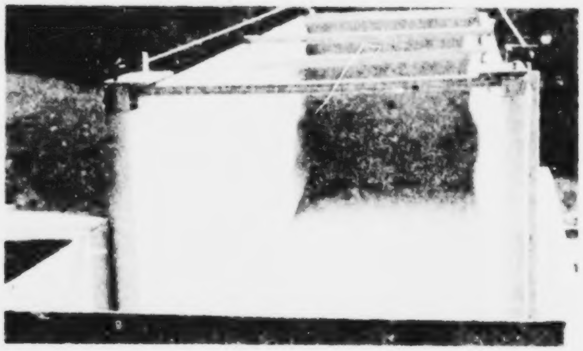
DEVELOPMENT OF THE SORBENT BROADCASTING SYSTEM

The objectives of this task were:

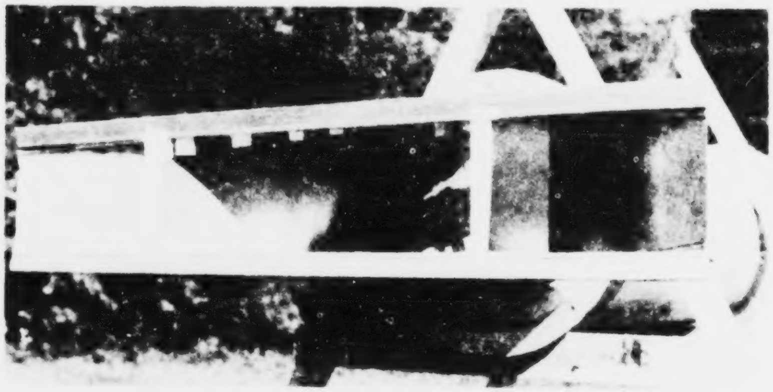
- To develop and demonstrate a means of evenly distributing sorbent material chips across the inner width of the recovery platform at its forward end.

- To develop and demonstrate a pneumatic system for conveying chips from the oil removal section of the recovery platform to the distribution device.

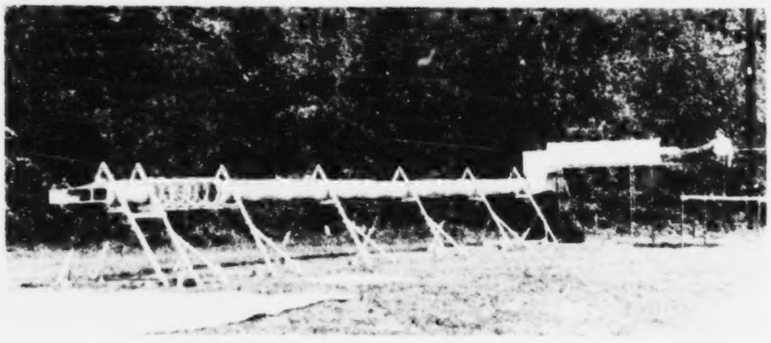
These objectives were accomplished with developmental model tests. Due to the specialized nature of the problem, the model size and other parameters were maintained at near full scale to reduce scaling uncertainties in the prototype design stage. Figure 3 shows an overall view of the experimental setup. The test program was directed at the development of a satisfactory broadcasting nozzle and at the measurement of the pneumatic conveying system performance.



INTERIOR OF FEEDER BOX



BASIC NOZZLE WITH TRIAL GUIDE VANES INSTALLED



OVERALL VIEW OF EXPERIMENT

FIGURE 3 - FULL SCALE SORBENT BROADCAST EXPERIMENT

For the purpose of the broadcasting experiments, it was assumed that a 100 percent nominal coverage of the slick would be required. Thus, using 3 in. × 3 in. square chips, for a slick thickness of 1.5 mm a recovery rate of 3000 GPH would require broadcasting 21,600 chips/minute. A rate of 10,000 GPH would require a rate of 72,000 chips/minute. Initial design studies indicated that, for the 10,000 GPH recovery unit, the sorbent broadcast pattern would have to be about 32 ft wide. It was hoped that a single passive nozzle with fixed guide vanes could achieve a uniform distribution with this width. However, the tests showed that, at near the design chip rate, a simple nozzle with fixed vanes would jam with chips. To overcome this problem, a movable parallel plate nozzle concept was developed. This nozzle produced satisfactory distribution patterns at the design chip rate. Figure 4 shows the nozzle installed on the experimental setup. Tests in wind showed some distortion of the broadcast pattern and indicated that the chip loss rate would be less than 5 percent of the broadcasting rate.

The pneumatic conveying system performance parameters were measured during the tests conducted for nozzle development. These performance parameters include the air speed necessary for good conveying, the head loss in the transport duct, the head loss across the fan, and the fan power required. These parameters were determined as a function of the ratio of the weight of sorbent material to the weight of air. During the tests, it was determined that the sorbent chips could be fed directly through a centrifugal blower equipped with a long shaving type wheel. Preliminary tests revealed that the chips should be stiff enough so that, upon contact with the wall of the transport ducts, they would not collapse and flatten completely against the wall. This implies a thickness of 1/4 in. to 3/8 in. for the 3 in. by 3 in. chips.

Based on the results of the test program, a design procedure was formulated for estimating the size, air flow rate, fan characteristics and power of a pneumatic conveying system. A more detailed description of the sorbent broadcasting system development program, including the test data, the design procedure and an example problem, is presented in Appendix B.

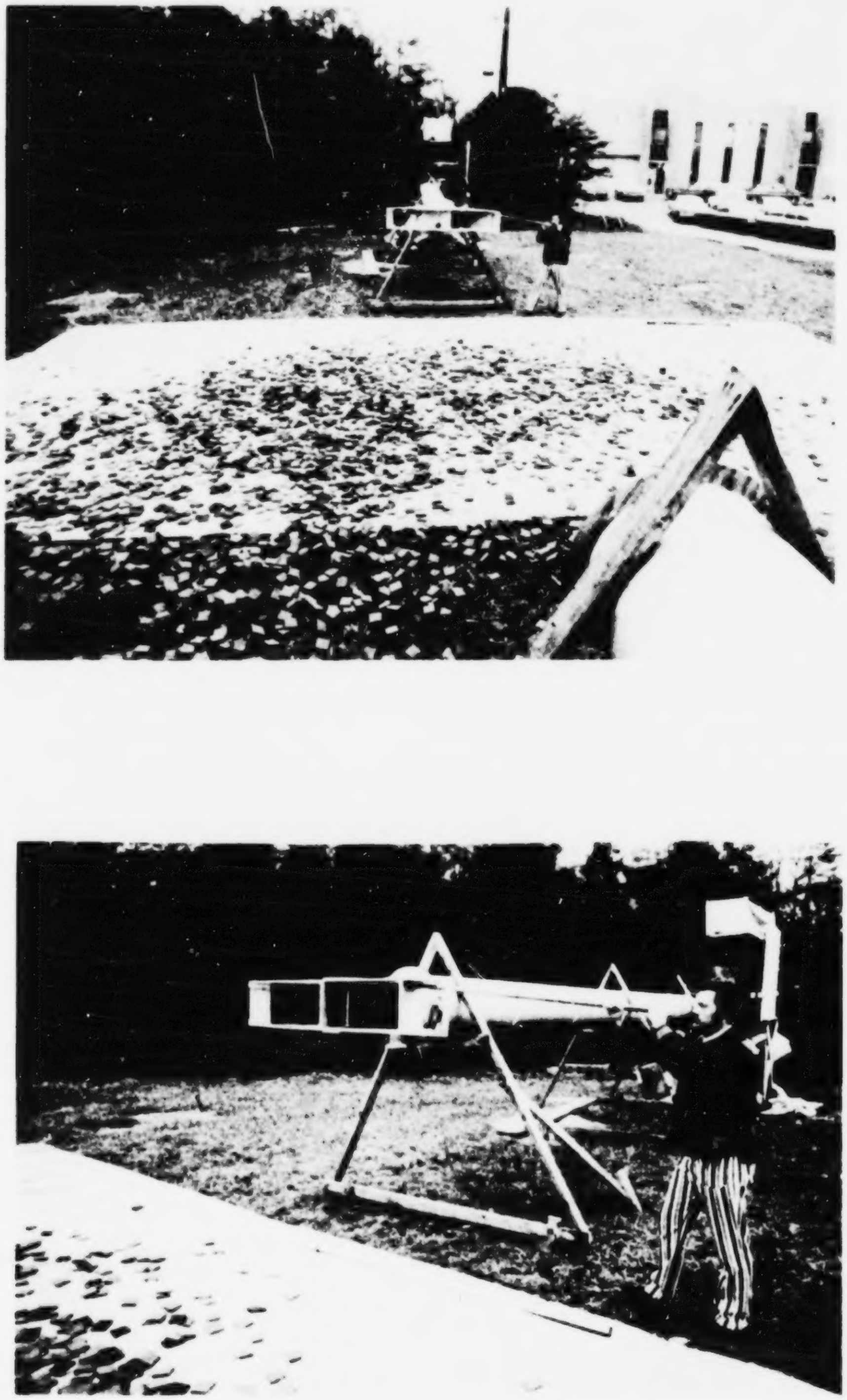


FIGURE 4 - THE MOVABLE PARALLEL PLATE NOZZLE AND THE BROADCAST PATTERN PRODUCED BY IT

The important results from this development task can be summarized as follows:

- A sorbent broadcasting system can be designed, based on a pneumatic conveying principle, which will meet the performance requirements and yet be of practical size.
- A movable parallel plate nozzle concept will produce a satisfactory broadcast pattern width and distribution.
- Wind will distort the broadcast pattern somewhat but the sorbent loss rate will be less than 2 percent of the broadcast rate.
- A rational design procedure was developed for selecting components for a pneumatic conveying system.

DEVELOPMENT OF THE HARVESTING CONVEYOR AND OVERALL OIL RECOVERY PERFORMANCE

The objectives of this task were:

- To determine the conveyor inclination angle and speed for optimum performance.
- To develop data on system performance as a function of the operating parameters, using the optimum conveyor operating condition.

The system performance was defined both in terms of the percentage of the oil in a slick which is recovered and the percentage of oil in the recovered fluid. The general and specific design goals supplied by the EPA request 100 percent recovery of the oil from the slick and in excess of 90 percent oil in the recovered fluid. The operating parameters which were studied in addition to the conveyor angle and speed included:

- Slick thickness and viscosity (oil type and temperature)

- Sorbent coverage
- Residence time
- Calm water versus waves

The objectives of this task were accomplished by means of an experimental program. In order to avoid scaling problems, the tests were carried out using typical oil products, full-size sorbent chips, and the actual conveyor belt material. The tests were conducted in a tank which is 80 ft long 2 ft wide and 2 ft deep. In effect this test setup was equivalent to a 2 ft wide strip along the centerline of the recovery system. Figure 5 is a photograph of the harvesting conveyor setup in the 80-ft tank. The conveyor material is 1 in. mesh-opening flat-wire belt. Figure 6 is a photograph of the carriage used to distribute the sorbent chips on the slick in the tank. The tests were conducted in accordance with the following procedure: First, a slick of known thickness was established on the water surface in the tank. The sorbent material was then distributed on the slick by the sorbent distribution carriage. After waiting the required residence time, the harvesting conveyor was run down the tank collecting the sorbent chips and dropping them in a collection box. Figure 7 shows a typical test in progress. After the run, the chips in collection box were regenerated and the amount of oil and water measured. The amount of oil remaining in the tank was also measured to determine the recovery performance or efficiency.

The first part of the test program was directed at determining the effects of conveyor-belt angle and speed on performance. Based on these tests, a conveyor angle of 45 degrees and belt speed equal to forward speed were selected for the remaining tests. These tests covered the range of parameters listed above. These data were reduced to parametric curves showing percent of oil recovery and percent oil in the recovered fluid as a function of the independent parameters. These curves may be used directly in the design and performance prediction of sorbent oil recovery systems. These curves and a more detailed description of this task are presented in Appendix C.

The important results from this development task can be summarized as follows:

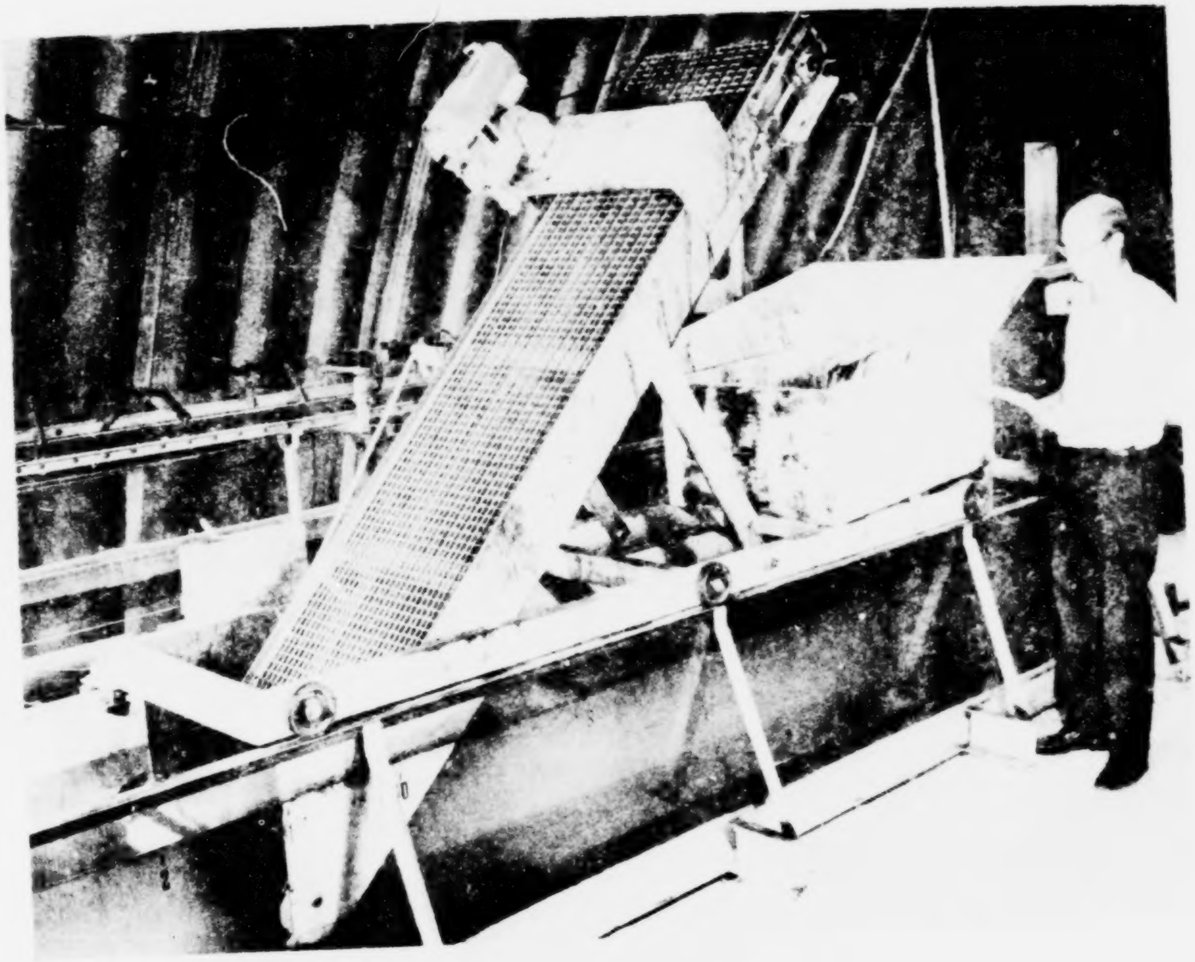


FIGURE 5 - HARVESTING CONVEYOR TEST SETUP

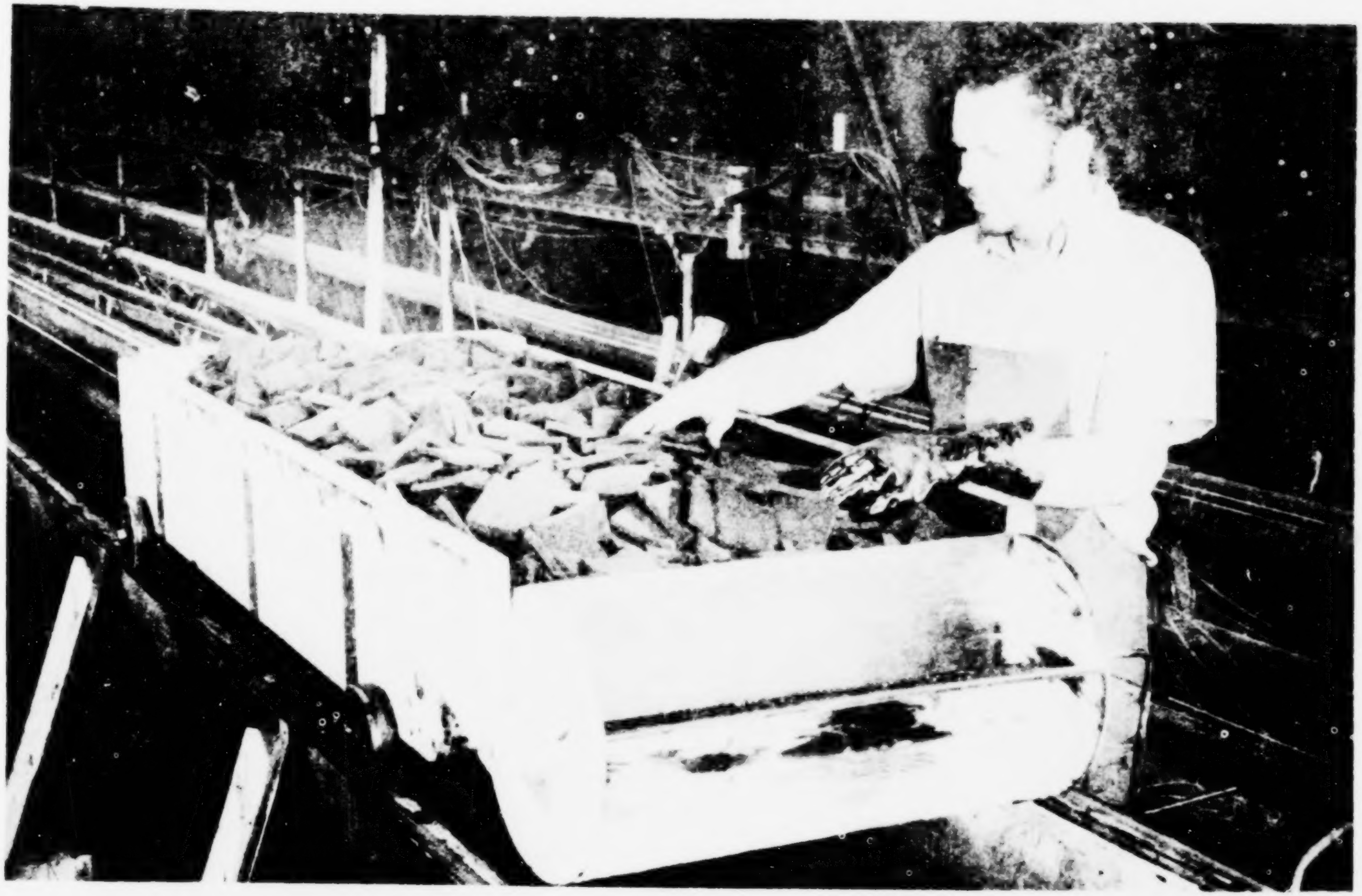


FIGURE 6 - SORBENT CHIP DISTRIBUTION CARRIAGE

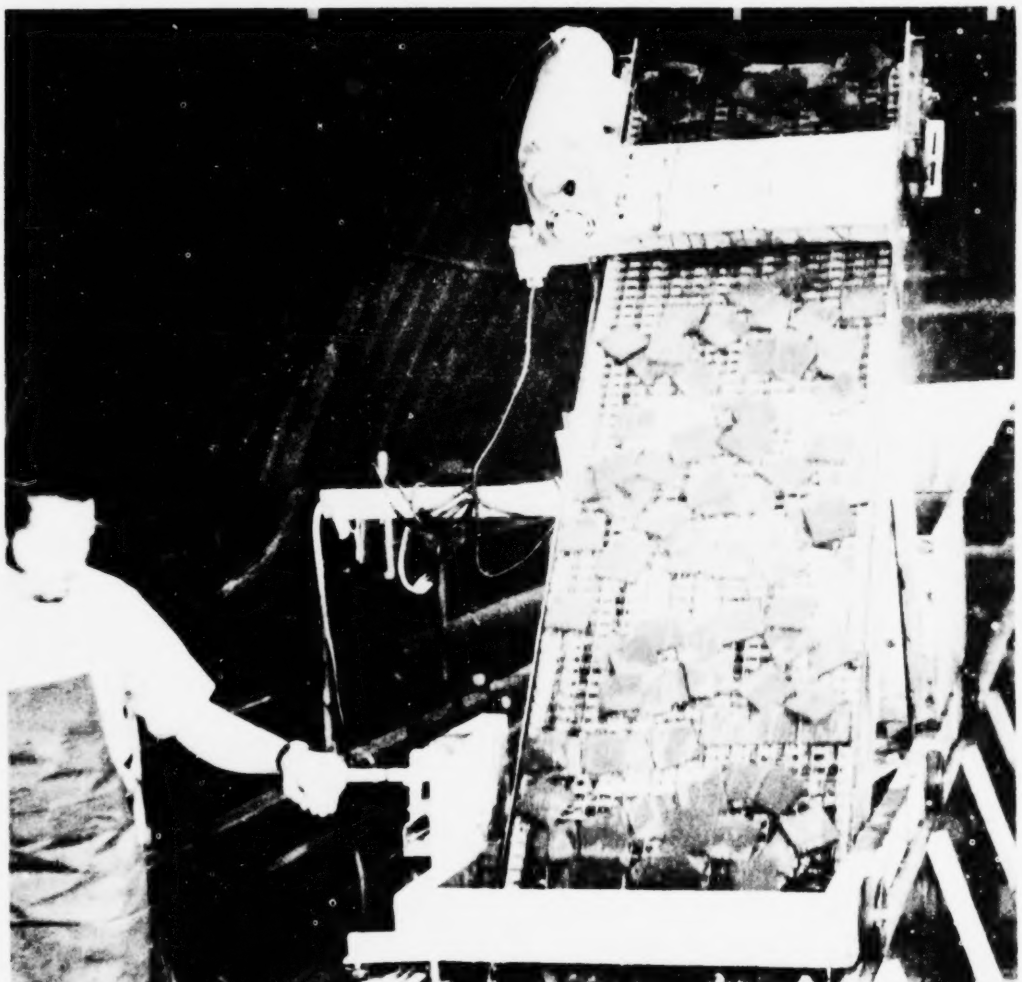


FIGURE 7 - HARVESTING CONVEYOR OPERATING IN WAVES

- A 1 in. mesh flat-wire belt will be satisfactory for the harvesting conveyor.
- The harvesting conveyor should be at an angle of 45 degrees and run at a belt speed equal to the forward speed.
- The oil recovery percentage will range from 90 to 95 percent over a wide range of oil types and slick thicknesses.
- The percent oil in the recovered fluid will meet the EPA goal of 90 percent for slick thickness of 1.5 mm.
- Waves will improve the oil recovery percentage relative to calm water because they agitate the sorbent causing it to contact a higher percentage of the slick surface.

DEVELOPMENT OF THE SORBENT REGENERATION SYSTEM

The polyurethane foam sorbent material can be regenerated for reuse simply by mechanically squeezing out the recovered oil. The sorbent regeneration system must perform this squeezing operation on a large enough volume of sorbent material to satisfy the required flow rate over the range of operational requirements. In effect, the sorbent regeneration system is the key element which makes a continuous cycle sorbent oil recovery system possible. The sorbent regeneration system is also the most complex mechanical component in the system.

The concept of a converging-belt squeezing device was selected for development as the sorbent regenerator. In this concept, the sorbent material is carried between two conveyor belts through a series of squeezing rollers. The upper conveyor belt converges with the lower belt at the entrance to the first pair of squeezing rollers. The upper belt is solid and the lower belt is porous so that the oil squeezed out flows through it into collecting pans. This concept was selected for the following reasons:

- A large volume of sorbent can be handled between small-diameter squeeze rollers.

- There is no relative movement between the belts and the sorbent which could damage the sorbent.

- The squeeze rollers can be mounted to allow large travel between them. This makes the regenerator tolerant of debris and drift wood which can run through the machine without causing damage.

- The physical dimensions of the resulting machine are compatible with the arrangement of the overall system.

A development task was carried out based on the converging-belt regenerator concept. The objectives of this task were:

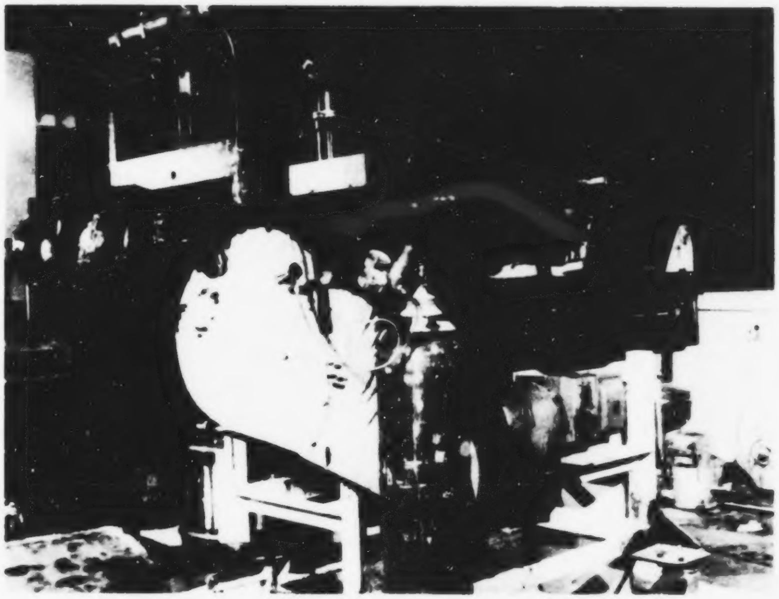
- Develop performance data for a converging belt sorbent regenerator as a function of the design parameters.

- Determine the effects of repeated cycles on the sorbent material.

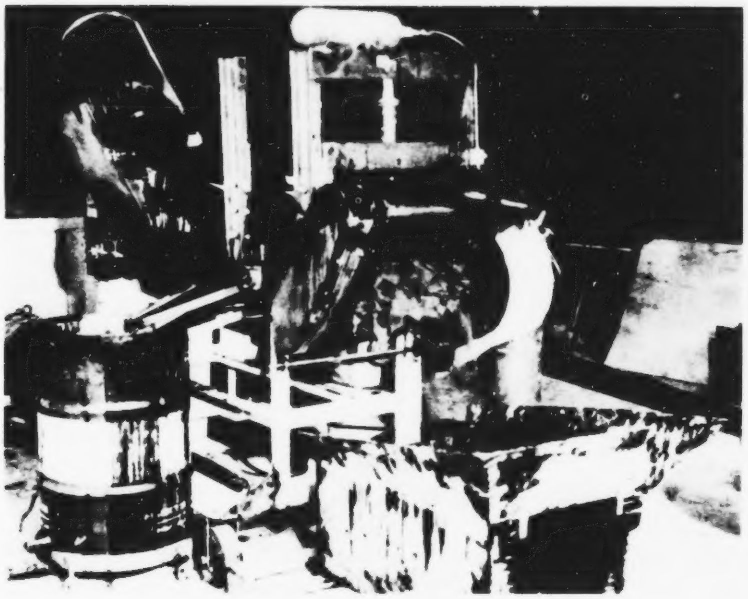
- Identify and resolve mechanical problems prior to the design of a prototype system.

These objectives were carried out by designing, building and testing a sorbent regenerator test apparatus. This test apparatus was about the same size and included many of the features of a sorbent regenerator for a 3000 GPH recovery unit. Figure 8 presents photographs showing overall views of the sorbent regeneration test apparatus and the system under test. The test is being carried out with 80 PPI foam and an oil mixture of 70 percent bunker "C" and 30 percent No. 2. The recovered oil can be seen flowing into the barrel. In a typical operating condition, the sorbent regenerator will have to remove about 2 gallons of oil per cubic foot of sorbent.

The broadcasting process which directly follows regeneration is sensitive to the density of the sorbent. Thus the performance of the sorbent regenerator is defined in terms of the density of regenerated sorbent from which 2 gallons of oil per cubic foot have been recovered.



Overall View of Test Apparatus



System Under Test

FIGURE 8 - SORBENT REGENERATOR TEST APPARATUS

The test program was carried out to determine the influence of various parameters on the density of the regenerated sorbent. These parameters included:

- Squeezing Force
- Belt Speed
- Sorbent Loading
- Sorbent Type
- Oil Viscosity

The results were plotted as parametric relationships which allow the selection of squeezing force, belt speed, sorbent loading and sorbent type for a given viscosity and required density. These parameters determine the mechanical characteristics of the sorbent regenerator. In addition, the test program covered endurance tests on the sorbent. Observations during the testing indicated several mechanical refinements which should be included on the prototype design.

Appendix D presents further details with respect to the sorbent regenerator development, test programs, data, and observations. The important results of this task can be summarized as follows:

- A converging-belt sorbent regenerator will satisfactorily regenerate sorbent chips at the volume rates required.
- The density of the regenerated chips will be about 6 lb/ft^3 for a squeezing force of 220 lb/in., a sorbent loading of 0.25 ft^3/ft^2 and a belt speed of 1 ft/sec.
- In order to maintain a 6 lb/ft^3 regenerated sorbent density, 30 PPI foam should be used for oil viscosities in excess of 1000 CPS.
- An oil viscosity of about 20,000 CPS at the time of regeneration is the practical upper limit because of the excessive density of the regenerated sorbent.
- The sorbent material can be cycled over 100 times without significant degradation.

MODEL TESTS OF A 1/4-SCALE MODEL RECOVERY PLATFORM

The objectives of this task were:

- To determine whether a continuous stable sorbent broadcast and recovery cycle is possible.
- To determine if there are any adverse effects of waves and forward speed on the continuous broadcast and recovery cycle.
- To determine the towing resistance and stability of the recovery platform at the deployment and operating draft.

The objectives of this task were satisfied by means of tests conducted on a 1/4-scale model of a recovery platform concept in the HYDRONAUTICS Ship Model Basin (HSMB®). The model was equipped with an operating broadcasting system and harvesting conveyor. No squeezing system was fitted on the model and no attempt was made to actually recovery oil. The recovery platform model was based on the concept presented in the original HYDRONAUTICS, Incorporated Sorbent Oil Recovery System Proposal. Subsequent preliminary sizing studies indicated that the basic concept and general proportions were still valid. Thus the model was sized to be a 1/4-scale model of a system intended to recover 10,000 gallons per hour. Figure 9 is a photograph showing the overall arrangement of the model.

Tests were conducted for both towing and pushing the recovery platform over a range of speeds up to 6 ft/sec full scale and over a range of wave heights up to a low Sea State 3 full scale. Measurements were made of the towing drag, speed, wave height and relative motions between the water surface and the platform. Observations and photographs were obtained of the sorbent distribution and collection. The data and detailed observations obtained from these tests, along with a more detailed description of the model and test procedures, are presented in Appendix E.

The important results from this development task can be summarized as follows:

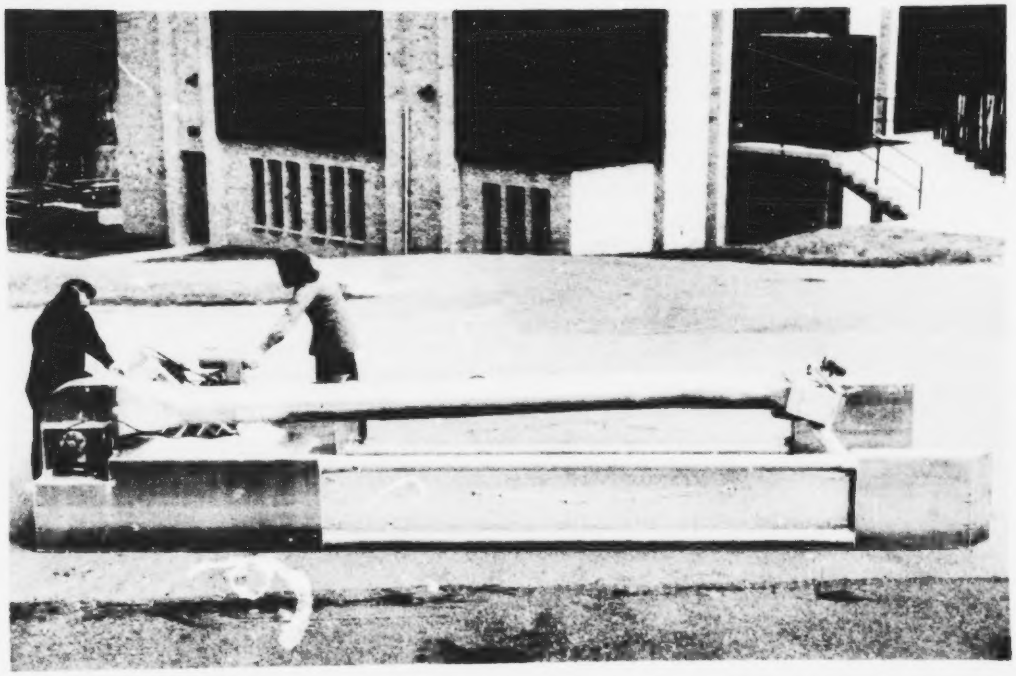


FIGURE 9 - OVERALL VIEW OF 1/4-SCALE MODEL SORBENT RECOVERY PLATFORM

- A continuous sorbent broadcasting and recovery operation with a uniform stable distribution of sorbent material can be achieved.
- The sorbent broadcasting and recovery operation will not be degraded by waves up to a low Sea State 3 and forward speed up to 6 ft/sec.
- The movable parallel plate broadcasting nozzle concept developed in a previous task provided a uniform transverse distribution of sorbent material.
- The sorbent material did not show any tendency to plug the inlet to the harvesting conveyor.
- The recovery platform can be towed up to a speed of 9.5 knots in the deployment condition.
- The recovery platform is directionally stable under tow.

SECTION V

SORBENT-OIL RECOVERY SYSTEM DESIGN

Based on the results of the development programs described in Section IV, design procedures have been defined for sorbent oil recovery systems and the results are presented in this section. These design procedures apply to continuous-cycle sorbent broadcast, recovery, regeneration systems. In order to minimize the effects of environmental parameters such as wind and waves it is intended that the sorbent material remain in unrestrained contact with the slick long enough to absorb the oil. The following discussion does not apply to systems in which the sorbent material is intended to form a cake or filter to remove the oil.

SYSTEM DESIGN PARAMETERS

The independent parameters which determine the characteristics of a sorbent oil recovery system are:

- Oil characteristics (i.e., viscosity)
- Slick Thickness
- Total Oil Recovery Rate
- Sweep Speed of the Recovery Platform
- Sorbent Residence Time
- Percent of Surface Covered by Sorbent

These parameters can be used to define the basic geometric parameters of the platform such as sweep width and active length, and operating parameters such as sorbent broadcast rate, broadcast distances and water recovery rate. In general, the first three parameters listed are specified as part of the specific design goals for the system; the system designer can select the last three parameters listed.

The percent of the surface covered by sorbent and the residence time determines the percent of oil recovered from the slick for given oil characteristics and slick thickness. The relationship between these parameters is illustrated in Figure 48 for typical conditions. With the percent oil recovery, the total slick area that must be swept per unit time to satisfy the total oil recovery rate can be calculated. The sweep rate (area per unit time) and the percent sorbent coverage define the sorbent broadcast rate. The sweep rate divided by the sweep speed gives the width of the sweep or sorbent broadcast pattern. The product of sweep speed and residence time gives the active length of the system. The active length is defined as the distance between the sorbent contact point with the slick and the harvesting conveyor.

The above shows that there are an infinite number of combinations of sweep speed, residence time and sorbent coverage which will satisfy a given set of specific design goals. As a result, other parameters must be introduced in order to produce a unique design solution. These parameters may include:

- Minimum cost
- Limitations on system or component dimensions
- Practical limits on the range of the independent parameters
- General design goals

In general, the procedure is to design for minimum cost within the limitations imposed by the other parameters. Table 2 lists typical limiting parameters except cost.

TABLE 2

Typical Limiting Parameters on a Sorbent-Oil Recovery System

Dimensions	Practical	General Design Goals
Limiting component length, width, height and weight for highway or air transport.	Residence times in excess of 30 seconds do not improve recovery percentage.	Maximum practical oil recovery percentage.
Overall length, width, height or draft of restricted areas (under piers, between ships).	Sorbent coverage in excess of 90 percent does not improve recovery percentage.	Others as listed in the Introduction.

In each case, the system designer must identify which of these limiting parameters apply and assign them a weight. Ideally the cost that should be minimized is the total life cycle cost per gallon recovered discounted to present value. In practice, this is not possible since the operating scenario, the social discount rate, and the social value of a gallon of recovered oil are not known. As a result, the simplified procedure of minimizing the sum of the capital and operating cost based on an assumed operating cycle has been adopted.

PLATFORM CONCEPT SELECTION

In the design of a sorbent-oil recovery system, a decision must be made as to whether to mount the system on a vessel of opportunity or on a specifically designed vessel or platform. In either case, the platform characteristics must be suitable for the recovery system equipment. Some of the desirable characteristics of a sorbent-oil recovery system platform are listed in Table 3.

TABLE 3

Desirable Recovery System Platform Characteristics

- Configuration which protects and confines sorbent material from wind effects during broadcasting.
- Configuration which channels the sorbent material to the harvesting conveyor.
- Location and support structure for harvesting conveyor.
- Unobstructed run for sorbent broadcasting duct.
- Location for mounting additional sweeping booms.
- Minimum relative motion in waves.
- Tankage for recovered oil.
- Acceptable towing resistance and directional stability.
- Ease of assembly and disassembly for transport.

A basic catamaran configuration has most of the desirable features listed in Table 3. In particular the area between the hulls provides a sheltered location for broadcasting the sorbent and channeling the sorbent to the harvesting conveyor. The harvesting conveyor can be mounted between the two hulls. The only advantage of a more conventional ship-like platform would be its lower towing resistance. Based on these considerations, if a platform is to be designed specifically for a sorbent-oil recovery system, it should be a catamaran configuration.

The selection of a vessel of opportunity or a specifically designed platform for mounting the recovery system depends on the design goals. Typical advantages of using either a specifically designed platform or a vessel of opportunity are listed in Tables 4 and 5, respectively.

TABLE 4

Advantages of Specifically Designed Recovery Platform

- Smaller Physical Dimensions
- Better Control of Broadcast Sorbent and Lower Sorbent Loss Rate
- Shorter Setup and Reaction Time
- Smaller Crew Required
- Lower Direct Operating Costs

TABLE 5

Advantages of a Vessel of Opportunity as Recovery Platform

- Simpler Transportation over long distances (only the recovery system equipment need be shipped)
- Lower Initial Cost

These tables indicate that, if the system is going to be used continuously, the operating efficiency and lower operating cost of a specifically designed platform would dictate its selection. This is the case for a harbor unit which will be used routinely to clean up small spills. The selection is not as clear for an unprotected water system which will be used only occasionally against larger spills. The specifically designed platform for the unprotected water recovery system described in Section VII, alone will cost between \$20,000 and about \$40,000 depending on whetner steel or aluminum construction is used. A system mounted on a vessel of opportunity would not require the special platform but would require 60 to 80 feet of open water containment barrier which could cost \$8000. The charter rate of a barge to mount the system on would be about \$100 per day. Thus the charter fee would equal the additional cost of this platform in between 120 and 320 operating days. Because of this and the increased efficiency of a specific platform, which is hard to quantify, the unprotected water system described in Section VII was based on a specifically designed recovery platform.

CALCULATION OF SYSTEM CHARACTERISTICS

To illustrate the procedures for selection of the system characteristics which are discussed above, the following example calculation for a protected water recovery unit is given:

PROTECTED WATER RECOVERY UNIT

Given: Recovery Rate, $\dot{\forall}_R$ = 3000 GPH
Slick thickness = 1.5 mm
Oil Viscosity < 6000 cps

Find: System characteristics for minimum cost
Oil volume per ft^2 of slick = 0.0368 gals/ft^2

Try: Residence time, T_R = 15 seconds
Sorbent coverage, C_s = 0.80
From Figure 48
Oil Recovery η_R = 0.87

Area to be swept/hour, A_s, $= \dfrac{\dot{V}_R}{0.0368 \times \eta_R} = 94{,}000$ $\mathrm{ft}^2/\mathrm{hr}$

Sweep speed = U_s, ft/sec

Sweep width, $W_s = A_s/U_s$ ft

Active length $L_A = U_s \times T_R$ = ft

A_c = Sorbent chip area in^2 t_c = sorbent chip thickness, in.

Sorbent broadcasting rate,

$$\dot{V}_s = \frac{A_s \times C_s \times t_c}{3600 \times 12}, \ \mathrm{ft}^3/\mathrm{sec}$$

Sorbent broadcasting rate,

$$\dot{N}_c = \frac{A_s \times C_s \times 144}{3600 \times A_c}, \ \text{chips/sec}$$

$\dot{V}_s = 0.436$ $\mathrm{ft}^3/\mathrm{sec}$

$\dot{N}_c = 334$ chips/sec

In order to select a sweep speed it is necessary to have a relationship for cost as a function of system geometry. It is assumed that the operating cost is essentially independent of the sweep speed and broadcasting rate. Thus it is only necessary to consider those parts of the first cost which are functions of sweep speed and broadcasting rate. In order to define the cost relationships it is necessary to carry out a concept design and cost estimate for the system. This has been done and the relationship for systems similar to the Harbor Unit presented in Section VI is:

$$\text{Relative Cost} = 22{,}000\left(0.80 \times \frac{L_A}{32} + 0.20 \times (W_s/16)^2\right)$$

$$+ 15000 \times \frac{\dot{V}_s}{0.44}\left(0.55 + 0.25 \times \frac{W_s}{16} + 0.20 \times \frac{L_A}{32}\right)$$

The first term is related to the recovery platform and the second term is related to the broadcasting, recovery and regeneration equipment. The relative cost as a function of sweep speed is:

Sweep Speed, U_s ft/sec	Sweep Width, W_s ft	Active Length, L_A ft	Relative Cost dollars
1.0	26.1	15	35,800
1.5	17.45	22.5	32,050
2.0	13.0	30.0	33,400

This indicates that for a 15-second residence time and 80-percent sorbent coverage that the optimum sweep speed is about 1.6 ft/sec. The effects of residence time and percent sorbent coverage can also be studied. For example, reductions in residence time to 10 seconds will reduce the relative cost about 2 percent. However, the oil recovery ratio drops to 0.75 which departs further from the general design goals of complete oil removal. Thus the optimum characteristics for a protected water sorbent oil recovery systems are:

Recovery Platform Type:	Catamaran
Sweep Speed	1.6 ft/sec
Sweep Width	16 ft
Active Length	24 ft
Sorbent Broadcast Rate	0.44 ft^3/sec

These characteristics will also satisfy the typical limiting parameters listed in Table 2. For example, the hull dimensions which will result from these characteristics are such that the two hulls can be carried side by side over the road. The overall dimensions of the assembled platform are comparable to those of other oil recovery craft, such as the M.V. Port Service of Baltimore, which work around piers and ships.

Once the basic system characteristics have been established, the detailed characteristics of the broadcasting and sorbent regeneration system can be determined using the procedures detailed in Appendices B and D.

SECTION VI

3000 GALLON PER HOUR RECOVERY SYSTEM PRELIMINARY DESIGN

A preliminary design of a sorbent oil recovery system for use in protected waters was prepared based on the general and specific design goals provided by the EPA. These specific design goals are given in Table 6.

TABLE 6

Specific Design Goals for Protected Water System

a. Environment

Perform effectively in harbors and other protected waters with 2-foot waves in combination with 20-mph winds and 6-knot currents.

b. Sorbent Recovery System

The sorbent recovery system in combination with necessary oil-water separation facilities shall have the capacity to recover at least 1,500 gal/hr of oil with 10 percent or less water content. However, a 3,000 gal/hr with 10 percent or less water content oil recovery rate would be a desired optimum rate.

(1) The sorbent system shall be capable of meeting the recovery rate objective while recovering oils with viscosities ranging from that of light diesel oil to near water density heavy asphalt at 20°C.

(2) The thickness of the slick to be recovered at the specified rate shall be 1.5 mm or less.

(3) The device may include as an integral part of the skimming process, a system of booms to aid in herding oil toward the harvesting device. However, emphasis shall be given to the skimming process rather than the design of the boom.

(4) Designed units proposed for temporary attachment to existing vessels must consider transport need and ease of installation with a minimum of special equipment.

c. Oil-Sorbent Separation

The unit must be capable of operating under hydraulic loadings and ranges of oil concentrations consistent with the performance of the oil harvesting devices. It must be capable of producing output streams with the following characteristics:

1. Oil - 10 percent water or less.

2. Sorbent material - available for reuse or method for disposal.

3. Water - 10 mg/l oil or less.

d. Oil Storage or Disposal

Specify floating or appropriate land-based facilities which in combination with any on-board storage will have capacity to store material to be collected from spills of at least 200,000 gallons of oil plus agglomerates. Agglomerates must be processed before land disposal to preclude leaching. Other appropriate disposal techniques such as incineration will be considered as alternatives.

e. Vessel

Recovery equipment may be designed for either permanent or temporary mounting on an appropriate vessel. Vessels must be capable of speeds of at least 12 knots under the environmental conditions listed above (however not performing the oil recovery function). The vessel must accommodate the oil-sorbent recovery device, any required oil-water separation equipment, operating personnel, eight hour fuel supply and all oil specified for storage on board. It must be sufficiently maneuverable to minimize time lost in recovering oil from constricted locations and be capable of operating in waters as shallow as 3-foot depth.

The system was designed to satisfy these desired recovery rates of 3000 GPH of heavy oil at 20°C. For design purpose, the heavy oil was taken as bunker "C" with a specific gravity of 0.98 and a viscosity of 4,500 centepoise at 20°C. The rationale for the selection of the system operating parameters such as sweep speed, sorbent coverage and sorbent residence time are presented in Section V.

GENERAL DESCRIPTION

The basic sorbent recovery system consists of a pneumatic broadcasting system with a moving parallel plate nozzle, a harvesting conveyor, a transfer conveyor, a sorbent regenerator, the necessary drive systems, and a catamaran type platform. The basic characteristics of the system are presented in Table 7. Figure 10 presents an overall arrangement drawing of the complete system. The sorbent material to be used and the recovery performance over a range of conditions are also given in Table 7.

RECOVERY SYSTEM COMPONENTS; BROADCASTING SYSTEM

The design of the pneumatic broadcasting system and broadcasting nozzle was based on the design procedures presented in Appendix B. This system is required to move and distribute 330 3 in. × 3 in. × 1/4 in. sorbent chips per second. The technical and performance characteristics of the broadcasting system are presented in Table 8. The system uses an off the shelf industrial fan with a long shavings type wheel. The only non-standard component in the system is the broadcasting nozzle. The nozzle plates are oscillated with a mechanical linkage driven by an air cylinder.

Harvesting and Transfer Conveyors

The harvesting conveyor is mounted between the hulls of the recovery platform. It has an overall width of 8.0 ft and a length between sprocket shafts of 9.0 ft. The conveyor is made up of two 4-ft wide belts. These belts are supported on their edges and centerlines by a support frame which also carries the sprocket shafts. The technical characteristics of the harvesting conveyor are presented in Table 9.

TABLE 7

Characteristics of Protected Water Sorbent-Oil Recovery System

Design Oil Recovery Rate	3000 gallons/hr
Slick Thickness	1.5 mm
Sweep Speed	1.6 ft/sec
Sweep Width (Normal)	16.0 ft
Sweep Width (Extension Booms)	32.0 ft
Active Length	24.0 ft
Sorbent Material	Open cell reticulated polyurethane foam
Sorbent Form	Chips 3 in. × 3 in. × 1/4 in. nominal
Sorbent Pore Size	
Oil Viscosity ≤ 1000 cps	80 PPI
Oil Viscosity > 1000 cps	30 PPI
Sorbent Residence Time	15 sec
Sorbent Coverage	80 percent

Oil Recovery Performance

1.5 mm Slick Thickness

Oil Viscosity cps	Oil Recovery Rate GPH	Oil Recovery from Slick percent	Water Recovery Rate GPH
≤ 6000	3000	87	311
10000	2830	82	270
20000	2580	75	243

Oil Recovery for Viscosity ≤ 6000 cps

Slick Thickness MM	Normal Sweep Width (16 ft) GPH	With Extension Booms (32 ft) GPH
0.5	1000	2000
1.0	2000	4000
1.5	3000	6000

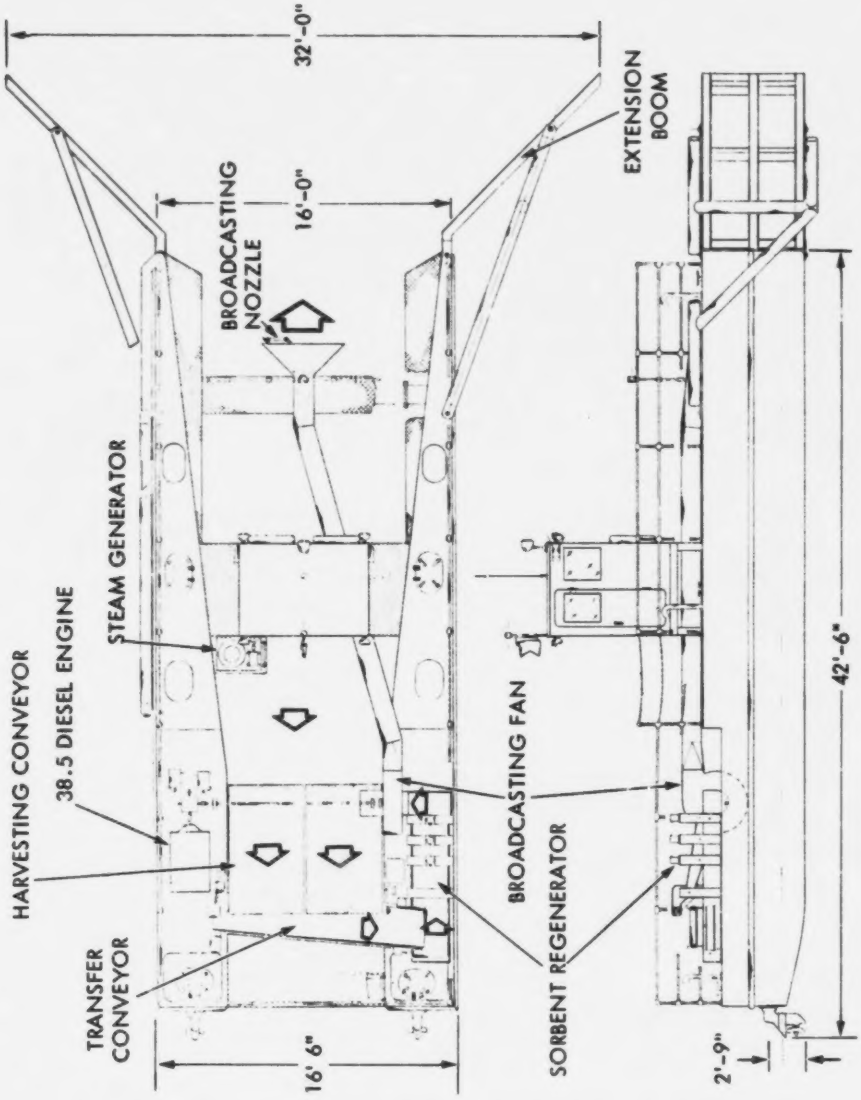

32'-0"
16'-0"
BROADCASTING NOZZLE
EXTENSION BOOM
STEAM GENERATOR
38.5 DIESEL ENGINE
HARVESTING CONVEYOR
TRANSFER CONVEYOR
BROADCASTING FAN
SORBENT REGENERATOR
16' 6"
42'-6"
2'-9"

FIGURE 10 - PROTECTED WATER RECOVERY SYSTEM ARRANGEMENT DRAWING

TABLE 8

Broadcasting System Characteristics

Sorbent Form	Chips 3 in. × 3 in. × 1/4 in. nominal
Sorbent Broadcasting Rate	0.424 ft^3/sec 330 chips/sec
Regenerated Sorbent Density	6.0 lbs/ft^3
Broadcasting Nozzle Type	Moving Parallel Plate
Nozzle Rate	1 cycle/sec
Nozzle Angle	±50 degrees
Nozzle Drive	Air Cylinder
Broadcasting Duct Diameter	1.0 ft
Broadcasting Duct Length	24.0 ft
Air Speed	45 ft/sec
Air Flow Rate	2062 ft^3/min
Fan Type	American Blower Series 106 Industrial Fan-Size 17 Long Shavings Wheel
Diameter (Wheel)	29-5/8 in.
RPM	1062
Fan Power (Total)	7.8 HP
Transmission	Mechanical
Total Sorbent in System	14.9 ft^3 11,450 chips

Sorbent Loss Rate

Wind Speed mph	Loss Rate ft^3/hr
0 - 10	3.1
10 - 20	15.5
20 - 30	31

The hydraulic drive system can provide an excess of 150 ft-lbs of torque at 47 rpm. This is sufficient to lift a combined weight of chips and debris of about 400 lbs. The belt material and sprockets for the conveyor are off the shelf items. The support frame will have to be fabricated.

TABLE 9

Harvesting Conveyor Characteristics

Conveyor Width	Total 8.0 ft - 2 sections 4.0 ft
Conveyor Angle	45 degs.
Conveyor Length	9.0 ft
Linear Belt Speed	1.6 ft/sec
Belt Material	1 in. × 1 in. mesh extra heavy duty (button head weld) flat-wire belt galvanized steel construction
Belt Drive	16 Class C sprockets 8-1/4 in. diameter - 23 teeth
Power	1.0 HP
Transmission	Hydraulic
Conveyor Support	Integral support frame

The transfer conveyor collects the chips from the harvesting conveyor and transports them to the sorbent regenerator. This conveyor has a belt width of 2.0 ft and a belt speed of 2 ft/sec. The requirements for this conveyor can be satisfied with commercial units which are available off the shelf. The detailed technical characteristics of the transfer conveyor are presented in Table 10.

TABLE 10

Transfer Conveyor Characteristics

Conveyor Belt Width	2.0 ft
Conveyor Length	11.5 ft
Linear Belt Speed	2 ft/sec
Belt Material	3 ply stitched canvas Neoprene covered
Conveyor Support	Troughed bed* with integral take up and driver pulley
Drive	8 in. pulley-friction drive
Power	1/2 HP
Transmission	Hydraulic

* Hytrol Conveyor Co. Model "TR" Horizontal Belt Conveyor or Equivalent.

Sorbent Regenerator

The preliminary design of the sorbent regenerator was based on the development work and data presented in Appendix D. The characteristics of the resulting unit are presented in Table 11. Figure 11 presents an arrangement drawing for the unit. The various elements are indicated in the figure. The design closely follows that of the sorbent regeneration test apparatus. The most important differences are the addition of a third pair of squeezing rollers and the use of a reinforced neoprene covered belt in place of the upper wire-mesh belt with pads. Other mechanical improvements suggested by the development program and detailed in Appendix D have been included. In addition, the collecting pan between the legs of the lower belt has been deepened and provisions made for heating coils. The development tests showed that cold bunker "C" (10^{o}C 20,000 cps) could be squeezed from the sorbent and through the lower belt. However, for satisfactory flow in the collecting pans the recovered oil must be heated. This will require about 1000 pounds of steam per hour. This steam can be supplied by a commercial steam cleaning unit.

TABLE 11

Sorbent Regenerator Characteristics

Design Sorbent Rate	0.43 ft^3/sec
Belt Speed	1.0 ft/sec
Maximum Squeezing Force	220 lb/in. of belt width
Number of Squeezing Stations	3
Squeezing Roller Width	24 in.
Squeezing Roller Diameter	6 in.
Lower Belt Material	Steel Balanced Belting Type B-60-32-14
Upper Belt Material	Reinforced Neoprene
Power	2 HP
Transmission	Hydraulic Drive
Air Supply	Engine Driven Compressor
Squeezing Force Generation	Air Cylinder
Squeezing Roller Travel	4 in.
Heating	Heating coils in collecting pan 1000 lb/hr steam

Sorbent Regeneration Performance

Oil Viscosity cps	Sorbent PPI	Squeezing Force lb/in	Regenerated Sorbent Density lb/ft^3
2	80	220	4.5
300	80	220	5.5
1000	30	220	5.0
4500	30	220	5.5
20,000	30	220	7.5

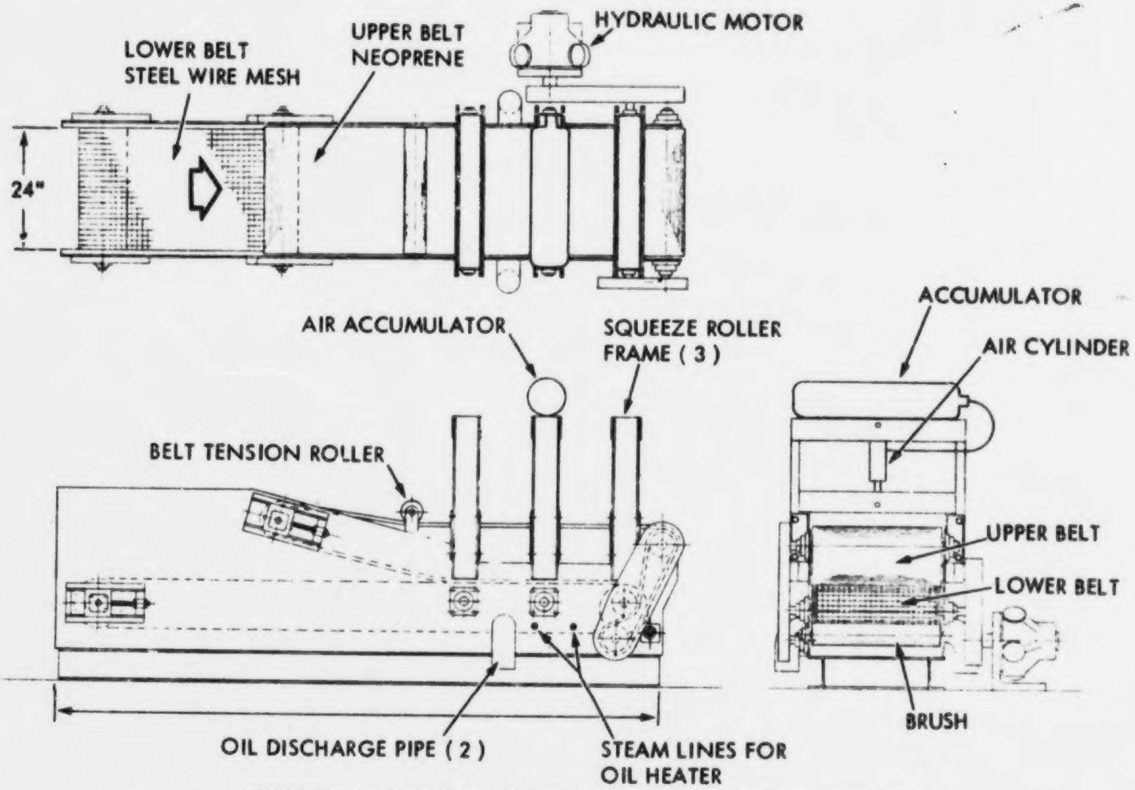

LOWER BELT
STEEL WIRE MESH
UPPER BELT
NEOPRENE
HYDRAULIC MOTOR
24"
ACCUMULATOR
AIR ACCUMULATOR
SQUEEZE ROLLER
FRAME (3)
AIR CYLINDER
BELT TENSION ROLLER
UPPER BELT
LOWER BELT
BRUSH
OIL DISCHARGE PIPE (2)
STEAM LINES FOR
OIL HEATER

FIGURE 11 - SORBENT REGENERATOR ARRANGEMENT DRAWING

Although the sorbent regenerator is the most complex mechanical element in the recovery system and is not a standard item, many of its components are commercially available. These include belts, air cylinder, shafts and bearings. The construction of the regenerator requires machine shop and light steel fabrication capabilities. These capabilities are readily available.

Miscellaneous Equipment

In addition to the main components of the recovery system, certain additional equipment are required to complete the recovery system. These include an oil transfer system to pump the recovered oil to storage, and a heating system for the sorbent regenerator and tank heating.

The oil transfer system will use a centrifugal pump driven mechanically off of the broadcasting system fan drive. The pump selected is a centrifugal pump, MP Model 130 or equal, bronze body, 188 gpm at 15 feet of head.

The heating of the tanks and sorbent regenerator, if required, is best provided by steam. Also steam may be required for cleaning. The most economical way of providing steam for these purposes is with a commercial steam cleaner unit. A suitable unit would be a Slifer Model 90 or equal with a capacity of 60 gph at 120 psi.

Power and Transmissions

The various components of the recovery system require a rugged and reliable power supply. For this purpose an independent power system consisting of a diesel engine with a hydraulic or combination hydraulic and mechanical transmission system was selected. The engine is a 38.5 HP radiator cooled Model 5034-7201 Detroit Diesel or equal. The radiator cooling makes the recovery unit independent of a supply of uncontaminated water for cooling and allows operation in cold weather by the addition of antifreeze.

The recovery system components consist of two types with respect to power transmission. The broadcasting system fan, the oil transfer pump, and the bilge and ballast pump (which is not part of the recovery system) require moderate powers at moderate rpm's. The harvesting and transfer conveyors and the sorbent regenerator require low power at low rpm's.

In both cases some independent speed control capability is desirable. As a result, it is desirable to have two separate power transmissions. The fan and pumps system could be either a direct mechanical or a hydraulic system. Diagrams for the mechanical and the hydraulic transmission systems are given in Figures 12 and 13, respectively. The mechanical transmission is less costly but restricts the arrangement of components. The hydraulic transmission is more costly but allows a much greater freedom with component arrangement. Both systems consist completely of commercial components which have a history of satisfactory operation. The hydraulic lines would be fitted with quick disconnect fittings which will allow rapid assembly and disassembly of the unit. In this case, a satisfactory arrangement can be made with the mechanical system so it is recommended because of the lower cost.

The transmission system for the sorbent regenerator and conveyor should be hydraulic. Hydraulic motors are available which are well suited to the required low rpm, high torque operation. Also a hydraulic system allows some speed adjustment and is much more easily arranged than a mechanical system. Figure 14 presents the flow diagram for the sorbent regenerator and conveyor hydraulic transmission. Again the system consists of commercial components with a history of satisfactory operation.

RECOVERY PLATFORM

The recovery platform is based on a catamaran concept with asymmetrical hulls configured to confine and herd the sorbent material. The harvesting conveyor is mounted between the hulls. Figure 10 presents an overall arrangement of the recovery system equipment and platform. The basic characteristics of the recovery platform are presented in Table 12.

Hull

The platform structure is composed of two asymmetrical hulls joined by two tubes. The tubes are fastened to the hulls with stainless steel bolts in such a manner that they can be disassembled for shipment. The hulls are each fitted with five watertight compartments for machinery, sorbent storage, recovered oil, and ballast. Figure 15 shows the internal arrangement of the hulls.

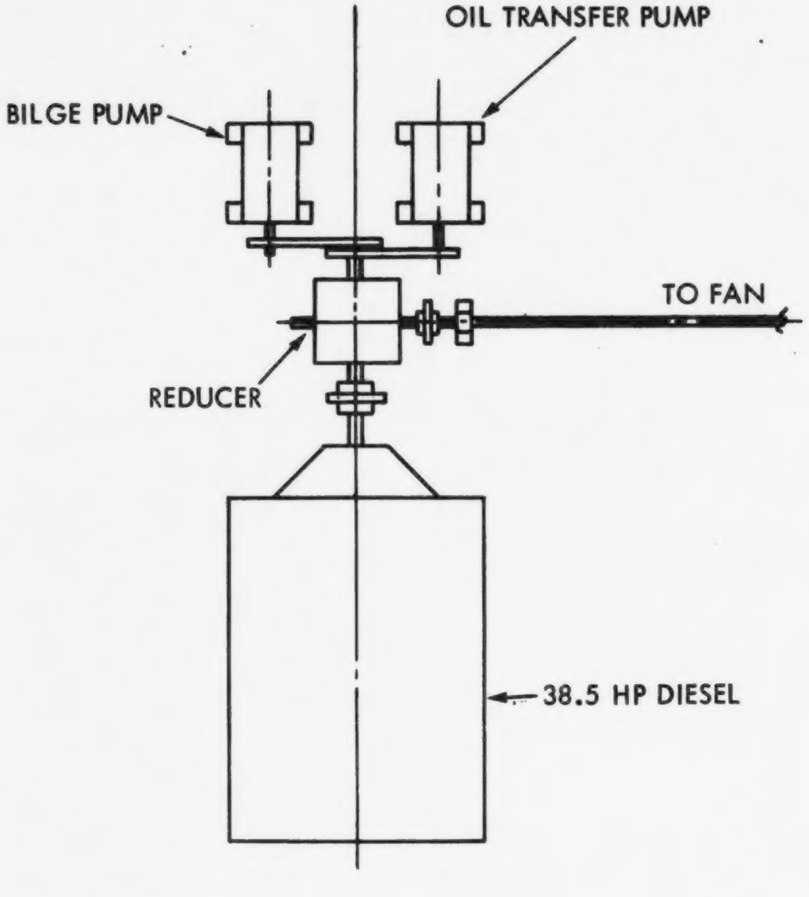

OIL TRANSFER PUMP
BILGE PUMP
TO FAN
REDUCER
38.5 HP DIESEL

FIGURE 12 - DIAGRAM OF FAN AND PUMP MECHANICAL TRANSMISSION FOR 3,000 GPH SYSTEM

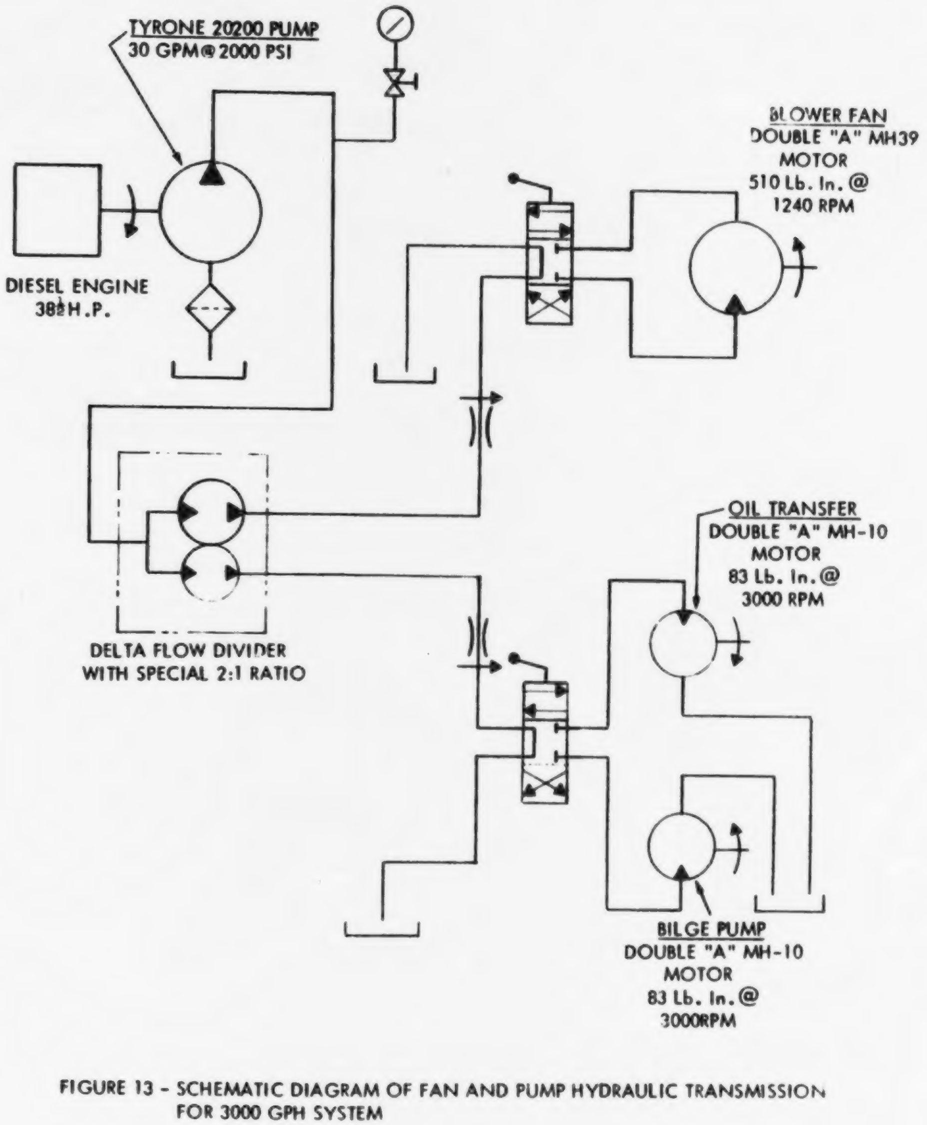

TYRONE 20200 PUMP
30 GPM@ 2000 PSI
DIESEL ENGINE
38½H.P.
BLOWER FAN
DOUBLE "A" MH39
MOTOR
510 Lb. In. @
1240 RPM
DELTA FLOW DIVIDER
WITH SPECIAL 2:1 RATIO
OIL TRANSFER
DOUBLE "A" MH-10
MOTOR
83 Lb. In.@
3000 RPM
BILGE PUMP
DOUBLE "A" MH-10
MOTOR
83 Lb. In.@
3000RPM

FIGURE 13 - SCHEMATIC DIAGRAM OF FAN AND PUMP HYDRAULIC TRANSMISSION FOR 3000 GPH SYSTEM

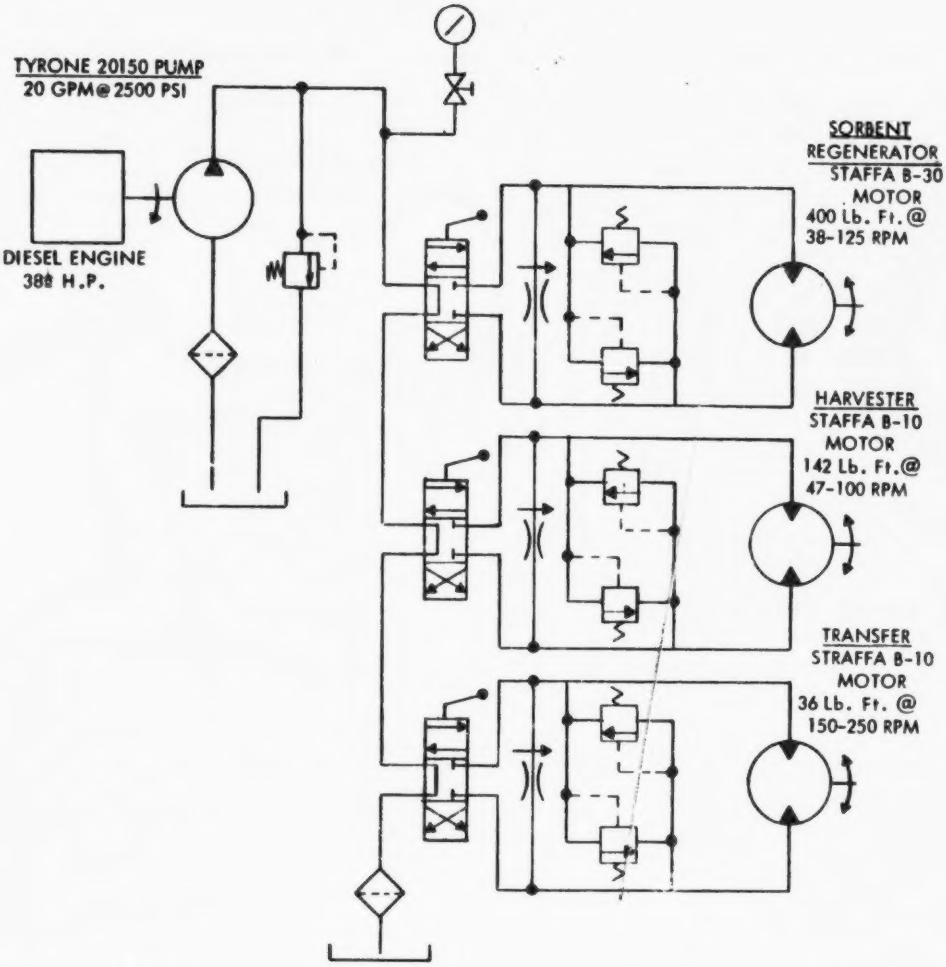

TYRONE 20150 PUMP
20 GPM@2500 PSI
DIESEL ENGINE
38½ H.P.
SORBENT
REGENERATOR
STAFFA B-30
MOTOR
400 Lb. Ft.@
38-125 RPM
HARVESTER
STAFFA B-10
MOTOR
142 Lb. Ft.@
47-100 RPM
TRANSFER
STRAFFA B-10
MOTOR
36 Lb. Ft. @
150-250 RPM

FIGURE 14 - SCHEMATIC DIAGRAM OF SORBENT REGENERATOR AND CONVEYOR HYDRAULIC TRANSMISSION FOR 3000 GPH SYSTEM

TABLE 12

Platform Characteristics

Platform Concept	Catamaran
Overall Length	42.5 ft
Overall Beam (Normal)	16.5 ft
Overall Beam (Extension Booms)	32.5 ft
Draft (Maximum)	3.0 ft
Hull Beam	4.25 ft
Hull Depth	5.5 ft
Hull Structure	Aluminum
Light Ship Weight	17,100 lbs
Service Loads	2,190 lbs
Recovered Fluid (3000 gallons)	22,610 lbs
Full Load Condition	41,900 lbs
Deployment Draft	1.33 ft
Full Load Draft	2.83 ft
Propulsion	2 - 75 HP Diesel I/O Drives
Deployment Speed	10.6 knots
Full Load Speed	8.4 knots
On Board Chip Storage	240 ft^3

Shipping Characteristics

Item	Length ft	Width ft	Depth ft	Estimated Weight lbs
2 hulls	42.5	4.5	8.0	6000 max.
2 cross beams	8.0	2.0	1.25	500
1 deck house	11.5	5.0	7.5	1200

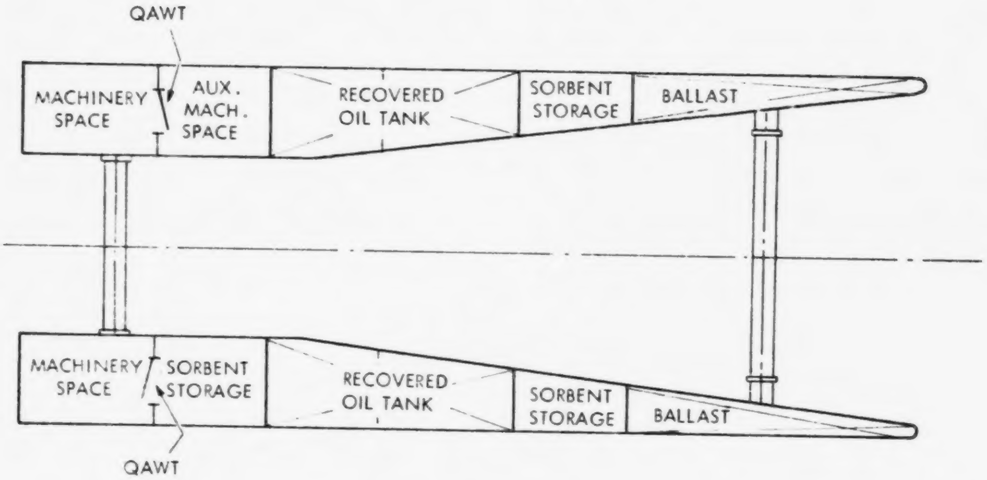

QAWT
MACHINERY SPACE
AUX. MACH. SPACE
RECOVERED OIL TANK
SORBENT STORAGE
BALLAST
MACHINERY SPACE
SORBENT STORAGE
RECOVERED OIL TANK
SORBENT STORAGE
BALLAST
QAWT

FIGURE 15 - INTERNAL ARRANGEMENT OF PLATFORM HULLS

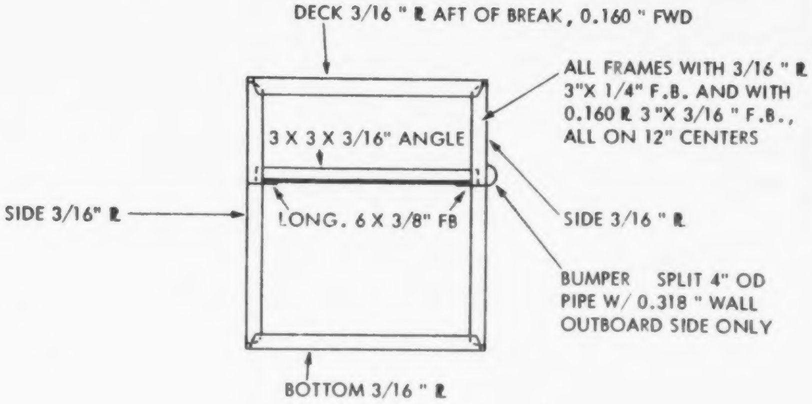
The hull structure can be either aluminum or steel. Aluminum has the advantages of lower weight for greater onboard oil storage and shipping, and lower maintenance costs. A steel hull will have a lower initial cost and higher weight. Aluminum construction including hulls, cross-beams, and the deck house will have a weight of 8600 lbs and a cost of $25,200 (each of 3). The comparable items in steel will have a weight of 20,000 lbs and a cost, with inorganic zinc coating, of $17,550 (each of 3). The characteristics presented in Table 12 are based on aluminum construction. Figure 16 presents a typical midship section for aluminum construction. As may be noted, the construction details are very simple so that the structure can be fabricated by any facility used to working with aluminum.

Propulsion

It has been assumed that the protected water sorbent-oil recovery system will be regularly used for cleaning up routine harbor spills. As a result, it is desirable to provide some form of self-propulsion rather than to use another vessel for towing or pushing. The speed-power curves for the recovery system at its full load and deployment draft are presented in Figure 17. The specific design goal of a deployment speed of 12 knots would require a total of about 240 HP. This power level exceeds the power available from lightweight propulsion systems. A reduction in speed to 10 knots reduces the required power to 125 HP which is within the practical range. The available lightweight and low-to-moderate cost propulsion systems include gasoline outboard motors or diesel inboard outdrives (I/O's). Inboard gasoline engines could provide higher power levels but could not satisfy U. S. Coast Guard Regulations for this type of craft.

The advantages of gasoline outboard motors include lightweight, low first cost, and good reliability. Their disadvantages are high operating cost and short life. For this application, two mercury Model 650 AC outboard or equivalent at about 80 HP each would be satisfactory. The advantages of diesel I/O's include low operating cost, good reliability and long life. However, they are heavier (about 1200 lbs) and more expensive (about $4700) than gasoline outboards. For this application two Volvo-Penta

BULKHEADS 0.160 " ⅊ w /3" X 3/16 " FRAMES ON 12" CENTERS


DECK 3/16 " ⅊ AFT OF BREAK, 0.160 " FWD
ALL FRAMES WITH 3/16 " ⅊ 3"X 1/4" F.B. AND WITH 0.160 ⅊ 3"X 3/16 " F.B., ALL ON 12" CENTERS
3 X 3 X 3/16" ANGLE
SIDE 3/16" ⅊
LONG. 6 X 3/8" FB
SIDE 3/16 " ⅊
BUMPER SPLIT 4" OD PIPE W/ 0.318 " WALL OUTBOARD SIDE ONLY
BOTTOM 3/16 " ⅊

STARBOARD HULL LOOKING FORWARD
8'-0" FORWARD OF TRANSOM
ALL WELDED 5086 - H111 AND H 32 ALUMINUM

FIGURE 16 -MIDSHIP SECTION FOR ALUMINUM CONSTRUCTION

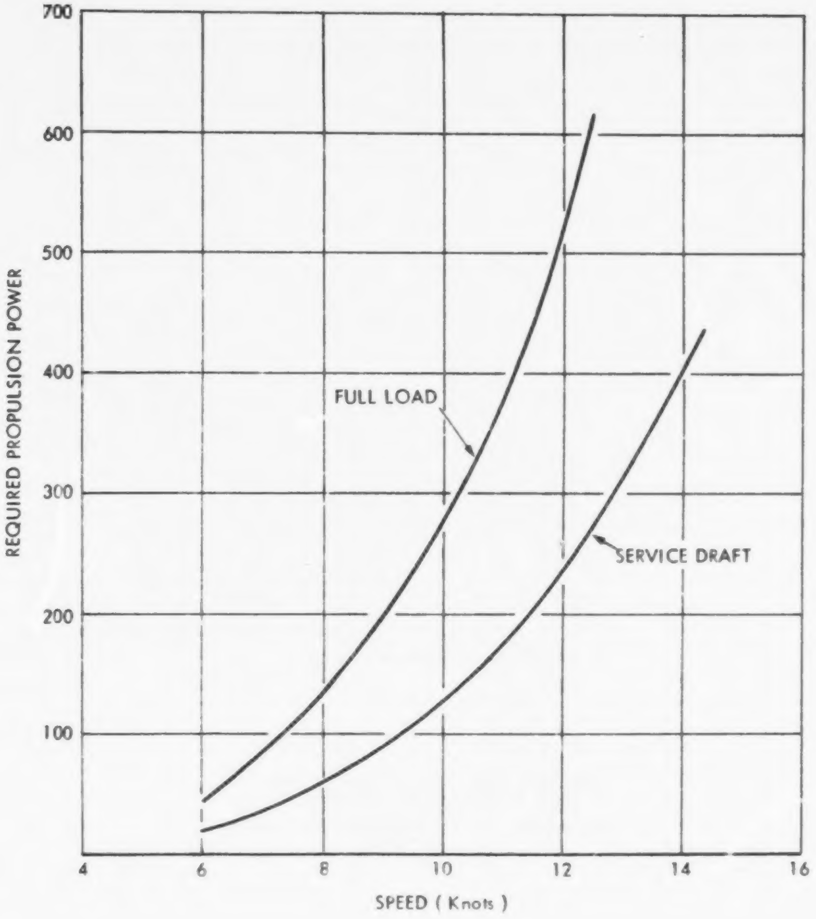


FIGURE 17 - SPEED POWER CURVES FOR PROTECTED WATER OIL RECOVERY UNIT

Inc. Model AQ D32A/270D or equivalent diesel outdrives at about 75 HP each would be satisfactory. If the recovery system is likely to be used on a daily basis it is recommended that the diesel outdrives be fitted. The arrangement drawing presented in Figure 11 is based on the use of diesel outdrives.

Outfit

In order to make the recovery platform an operational system, a certain amount of outfit is required. The typical outfit items are listed in Table 13.

TABLE 13

Outfit Items

Railings	Lockers
Hatches	Cleats
Anchor and Lines	Piping
Fenders	Chemical Toilet
Fire Extinguishers	Compass
Lights	Radio

The extent of the outfit depends on the service the recovery platform will see and the requirements of the particular owner.

WEIGHT ESTIMATES

A detailed weight estimate was prepared and is presented in Table 14. This weight estimate is based on aluminum construction and propulsion with diesel outdrives. If steel structure is used instead of aluminum, the total structural weight would increase to about 20,000 lbs. This would reduce the amount of recovered oil which could be carried at a draft of 2.75 ft to about 1350 gallons.

TABLE 14

Weight Estimate for 3000 GPH Protected Water Sorbent-Oil Recovery System

CALCULATION OF WEIGHT

1 of 4

SHIP Protected Water Unit	WEIGHT IN	ABOVE MLD BASE LINE		REFERRED TO: Transom			
ITEM Structure	lbs	C.G.	VERT. MOM.	C.G.	FWD MOMENTS	C.G.	AFTER MOMENTS
Bottom	620						
Deck	756						
Sides	2046						
Transom	17[illegible]						
Bulkheads	330						
Longitudinal Web	[illegible]						
Rub Rail	104						
Fwd. Beam	410						
Aft. Beam	216						
House	84[illegible]						
Grating	468						
Miscellaneous	1000						
Total Structure	8600				169,[illegible]		
Mechanical Systems							
Squeezer	700						
Fan	465						
Harvesting Conveyor	500						
Broadcast Duct	320						
Hydraulic and Mechanical Drive	1150						
Diesel	1200						
Total Mechanical Systems	4335				46,205		

DATE | COMPUTED | CHECKED | BOTH SIDES

TABLE 14 (Continued)

2 of 4

CALCULATION OF WEIGHT

		WEIGHT IN	ABOVE MLD BASE LINE		REFERRED TO: Transom			
SHIP	Harbor Recovery Unit	lbs						
ITEM	Outfit		C.G.	VERT. MOM.	C.G.	FWD MOMENTS	C.G.	AFTER MOMENTS
	Railings	170						
	Hatches	200						
	Anchor	125						
	Fenders	150						
	Fire Extinguishers	200						
	Lights	50						
	Lockers	50						
	Cleats	50						
	Piping	450						
	Chemical Toilet	50						
	Compass	10						
	Radio	30						
	Miscellaneous	140						
	Total Outfit	1585				31539		
	Propulsion Machinery							
	2 Diesel I/O's with power tilt, Steering Battery, fuel tank	1620				3240		
DATE	COMPUTER	CHECKED					NAVSHIPS	

TABLE 14 (Continued)

CALCULATION OF WEIGHT

3 of 4

SHIP Harbor Recovery Unit

ITEM Service Load

ITEM	WEIGHT IN lbs	ABOVE MLD BASE LINE		REFERRED TO: Transom			
		C.G.	VERT. MOM.	C.G.	FWD MOMENTS	C.G.	AFTER MOMENTS
Fuel-Diesel	600						
Personnel and Effects	500						
Sorbent Chips	600						
Fresh Water	150						
Total Service Load	1950				28000		
Cargo - 3000 Gallons at 7.5 lb/gal							
Recovered Oil	22610				358000		

DATE

COMPUTED

CHECKED

[illegible]

TABLE 14 (Concluded)

CALCULATION OF WEIGHT

4 of 4

SHIP Harbor Recovery Unit	WEIGHT IN	ABOVE MLD BASE LINE		REFERRED TO Transom			
ITEM Summary	lbs	C.G.	VERT. MOM.	C.G.	FWD MOMENTS	C.G.	AFTER MOMENTS
Structure	[illegible]						
Mechanical Systems	[illegible]						
Outfit	[illegible]						
Provision for Margin	[illegible]						
Margin	[illegible]						
Light Ship	16065			15.[illegible]	[illegible],000		
[illegible]	[illegible]				[illegible],000		
Service Condition(Draft = [illegible] ft)	[illegible]			15.[illegible]	[illegible],000		
[illegible] Oil ([illegible] Gallons)	[illegible]10			15.[illegible]	[illegible],000		
Full Load Condition (Draft = [illegible] ft)	[illegible]			15.[illegible]	[illegible],000		
DATE	COMPUTED		CHECKER			BOTH SIDES	

Reproduced from best available copy.

CREW AND OPERATING PROCEDURES

The protected water sorbent-oil recovery system should be operated by a three-man crew consisting of a captain. engineer and deck hand. The duties of these crew members are listed in Table 15. Although the sorbent broadcasting, recovery. regeneration cycle is an automatic one, some assistance will be required from the crew. The most important is the removal of large pieces of debris and driftwood picked up by the harvesting conveyor. These items would be removed from the transfer conveyor or the inlet of the broadcasting fan. Also the crew must introduce the sorbent material at the start of the operation or makeup sorbent during the operation. The sorbent material will be pre-cut and stored aboard in bags. It is introduced into the system by dumping it on the transfer conveyor with all components running. If the slick is thin or discontinuous. the sorbent should be prewetted with the diesel oil carried onboard. This will limit the amount of water recovered. At the end of the operation. the sorbent material is recovered by stopping the broadcasting system and collecting the sorbent in bags as it comes out of the regenerator.

On arrival at the scene of a spill, the sweeping booms are extended, if required, and the sorbent material introduced to the system. The recovery platform is then driven into the slick and continues sweeping at the selected speed until the slick is recovered. Since the operation is independent of platform draft, no ballasting is required. If the slick is in a restricted area, such as between a ship and pier, a different operating procedure will be required. The recovery platform would be positioned in the slick and stopped.

The sorbent material would then be herded back to the harvesting conveyor by the crew using rakes. Operating in this manner, the recovery rate would be much less than the design rate.

When the oil tanks are full, the oil-transfer system would be used to pump out onto an accompanying barge or at a shore-side facility. At the conclusion of the recovery operation, the sorbent material is recovered for reuse and the equipment cleaned and repaired as required. Much of the sorbent that is lost during the recovery operation may be expected to remain in the area of the spill. This sorbent

TABLE 15

Duties of Recovery System Crew

Captain

- Direct the oil recovery operation
- Control the speed and location of the recovery platform

Duty Station: Pilot House

Engineer

- Control Recovery Machinery
- Repair and Maintain Machinery
- Operate Oil Transfer and Ballast System
- Assist Deck Hand

Duty Station: Recovery Machinery Controls, Port Side Aft.

Deck Hand

- Introduce Sorbent Material into System
- Remove Larger Pieces of Debris from Transfer Conveyor
- Repack Sorbent Material
- Handle Lines

Duty Station: Grating aft of transfer conveyor.

can be recovered by resweeping the area with the broadcasting system off. This will require an expenditure of personnel time but may be required and could be economically desirable if the sorbent losses are large (high winds). The resweeping operations could be carried out at a higher speed than the basic recovery operation.

COST ANALYSIS

A detailed analysis was made of the construction and operating costs of the 3000 GPH protected water recovery system. The following assumptions were used in this analysis:

- The costs apply only to "following systems" after a prototype system has been proven and a complete corrected set of specifications and plans are available.
- The estimates are based on construction in flights of 1 and 3 units.
- The builder is to be experienced with all types of fabrications and machinery installation required and the facility is to be equipped to handle this size job. Experience is required in steel or aluminum fabrication, diesel-hydraulic machinery, and workboat outfitting to USCG regulations.
- Only commercial quality construction is required without extensive reference to government specifications or special inspection.
- Costs are based on Spring 1972 dollars.

The construction cost estimates were made by summing the total cost of purchased components and the value of the man hours needed to assemble these components. A man-hour was valued at $12.00 including overhead and profit. In the case of the platform structure, budget prices were obtained from fabricators based on preliminary drawings. The sorbent material has a basic cost of $6.60 per ft^3 in bulk form. The material can be cut into chips with a band saw at the rate of about 4000 chips/hr. This gives a total cost of $9.20 per ft^3 cut into chips.

The construction cost will depend on the type of structure, the type of propulsion, and the extent of the outfit. The selection of these items depends on the intended duty and the importance of initial cost. The construction cost data are presented in Table 16 for the various system elements. Various possible cost options are presented in Table 17 ranging from minimum initial cost to the complete system fitted for independent operation. The arrangement drawings, characteristics tables and weight estimates presented above are for the complete system fitted for independent operation.

The recovery machinery is common to all users and is the heart of the system. As a result, a detailed analysis of the recovery machinery construction cost estimate is given in Table 18.

The operating costs will depend on how and by whom the recovery system is operated. The direct operating costs were estimated on a per hour of effective oil recovery and per hour of deployment time. The results are presented in Table 19 and are based on a crew cost of $10. per man hour. Costs are given based on a 10 to 20 MPH wind and no attempt to recover sorbent and on a resweep of the slick area which recovers 70 percent of the lost sorbent. If the recovery operation were carried out by a spill control contractor a charge would be made to cover the capital cost of the equipment. Typical rates currently charged are 0.0025 times initial cost per hour. This would amount to between $100 and $175 per hour depending on the unit used.

It is of interest to note that even when 70 percent of the sorbent is recovered, about 65 percent of the direct operating cost is associated with the recovery and replacement of lost sorbent. This could pay for a considerable increase in platform cost to reduce the sorbent loss rate.

TABLE 16

3000 GPH Protected Water Recovery System
Cost Analysis

Summary Harbor Recovery Unit	Dollar Total for 1			Dollar Total ea of 3		
	Material	MH	Total	Material	MH	Total
Recovery Unit - Installed and Operating:						
Combined Mechanical and Hydraulic Drive	14090.	668.	22110.	12400.	587.	19450
Full Hydraulic Drive	15060.	64[illegible].	22780.	13240.	567.	20040.
Hull -						
Open Operating Station: Steel	13000.	-	13000.	11700.	-	11700.
Steel with inorganic zinc coating	17000.	-	17000.	15300.	-	15300.
Aluminum	24500.	-	24500.	22050.	-	22050.
Enclosed Operating Station: Steel	15000.	-	15000.	13500.	-	13500.
Steel with inorganic zinc coating	19500.	-	19500.	17550.	-	17550.
Aluminum	28000.	-	28000.	25200.	-	25200.
Outfit -						
Minimum - Steel	[illegible]00.	[illegible]8.	[illegible]70.	[illegible]80.	218.	4900.
- Aluminum	3030.	[illegible]8.	[illegible]010.	[illegible]70.	218.	5290.
With enclosed house: - Steel	[illegible]0.	30[illegible].	9500.	5150.	269.	8380.
- Aluminum	7580.	30[illegible].	11250.	[illegible]70.	269.	9900.
With enclosed house and self propulsion - Steel	67[illegible].	358.	110[illegible].	5950.	315.	9730.
- Aluminum	8[illegible].	358.	1[illegible]0.	7610.	315.	11390.
Independent Operation - Steel	75[illegible].	[illegible]00.	1[illegible]0.	6890.	350.	11110.
- Aluminum	9000.	[illegible]00.	1[illegible]700.	8700.	350.	12900.
Propulsion						
Twin Diesel I/O	7330.	[illegible]0.	[illegible].	7050.	72.	7910.
Twin Outboards	[illegible]370.	[illegible]0.	3470.	[illegible]730.	[illegible]8.	3310.
Supply of Sorbent Material ([illegible] ft)	[illegible]10.	-	[illegible].	[illegible]210.	-	[illegible]210.

TABLE 17

3000 GPH Protected Water Recovery System
Total Construction Costs

	Dollar Total for 1	Dollar Total Each of 3
Minimum Initial Cost:		
Recovery Unit - Combined Mechanical and Hydraulic Drive	22110.	19450.
Uncoated steel hull	13000.	11700.
Minimum outfit (steel) w/o sweep booms	5570.	4900.
Outboard motor propulsion	3470.	3310.
Total w/o sorbent material	44150.	39360.
Sorbent material	2210.	2210.
Total with sorbent material	46360.	41570.
Minimum Intermittent Duty:		
Recovery unit -combined mech. and hydraulic drive	22110.	19450.
Coated steel hull (open operating station)	17000.	15300.
Outfit (open operating station)	5570.	4900.
Outboard motor propulsion	3470.	3310.
Total w/o sorbent material	48050.	42960.
Sorbent material	2210.	2210.
Total with sorbent material	50,260.	45170.
Minimum Continuous Duty Unit:		
Recovery unit-combined mechanically and hydraulic drive	22110.	19450.
Aluminum (open operating stat.)	24500.	22050.
Outfit (open operating station).	6010.	5290.
Twin Diesel Propulsion	8790.	7910.
Total w/o sorbent material	61410.	54700.
Sorbent material	2210.	2210.
Total with sorbent material	63620.	56910.
Independent Operating Unit:		
Recovery unit - Full hydraulic Drive	22780.	20040.
Aluminum Hull, enclosed house	28000.	25200.
Outfit - Independent operation	14700.	12920.
Twin Diesel Propulsion	8790.	7910.
Total w/o sorbent material	74270.	66070.
Sorbent material	2210.	2210.
Total with sorbent material	76480.	68280.

TABLE 18

Detailed Analysis of Protected Water Unit Recovery Machinery Cost

A. Oil Recovery Machinery
(Cost of materials and fabrication of components including hydraulic system hook-up)

Squeezer	$3000.	210 MH	fabricated
Fan	550.	-	purchase complete
Harvesting conveyor	1400.	50	fabricated
Broadcast duct	200.	-	purchased
Broadcast nozzle	40.	16	fabricated
Transfer conveyor	600.	8	purchased
Hydraulic drive	5300.	48	purchased components and hook-up required
Mechanical drive	500.	8	purchased components and hook-up required
Diesel	[illegible]100.	40	purchased complete
Transfer pump	130.	-	purchased
Total for 1	14090.	380	
Total each for 3 @ .88	12400.	334	
Additional for full hydraulic drive	960.	+24	
Total for 1	15050.	404	
Total each of 3 @ .88	13240.	356	

Install and trouble-shoot recovery system (hydraulic and Mech)

Total for 1	-	288	
Total for each of 3	-	253	(full hydraulic system)
Total for 1	-	240	
Total each of 3	-	211	

TABLE 19

3000 GPH Protected Water Recovery System Direct Operating Costs

Per Hour of Effective Oil Recovery:		
No lost sorbent recovery[1]		
Crew	$30.00	
Maintenance	10.00	
Sorbent	142.50	(10-20 MPH wind)
Fuel and Miscellaneous	10.00	
Total	$192.50	
70 Percent Lost Sorbent Recovery on Second Sweep:[2]		
Crew	60.00	
Maintenance	20.00	
Sorbent	42.75	
Fuel and Miscellaneous	15.00	
Total	$137.75	
Per Hour of Deployment:		
Crew	30.00	
Maintenance	4.00	
Fuel and Miscellaneous	7.50	
Total	$41.50	

[1] No attempt is made to recover the sorbent material lost due to wind.

[2] A second sweep of the slick area is made with the broadcasting system off to recover sorbent material. It is assumed that 70 percent of the sorbent which was lost is recovered by this procedure.

SECTION VII

10,000 GALLON PER HOUR RECOVERY SYSTEM PRELIMINARY DESIGN

A preliminary design of a sorbent-oil recovery system for use in unprotected waters was prepared based on the general and specific design goals provided by the EPA. These specific design goals are given in Table 20.

TABLE 20

Specific Design Goals for Unprotected Water System

Unprotected Waters

a. Environment

Perform effectively in waters with up to 5-foot seas in combination with 30-mph winds and 2-knot currents, close to shore in less than 80-foot depths.

b. Sorbent Recovery System

The sorbent recovery system in combination with any necessary oil-water separation facilities shall have the capacity to recover at a minimum rate of 10,000 gal/hr of oil with 10 percent or less water content.

(1) The water content objective may be altered if this is consistent with the method of ultimate disposal of the oil.

(2) Oil-sorbent separation may be accomplished either as an inherent characteristic of the recovery device or an individual unit process.

(3) The device shall be capable of meeting the recovery rate objective while recovering oils with viscosities ranging from that of light diesel oil to Bunker C oil at 20°C.

(4) The thickness of the slick to be recovered at the specified rate shall be 1.5 mm or less.

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TABLE 20 (Continued)

(5) The device may include as an integral part of the skimming process, a system of booms to aid in herding oil toward the harvesting device.

(6) Design of units to be temporarily attached to existing vessels must consider transport needs and ease of installation with a minimum of special equipment.

c. Oil-Sorbent Separation

The unit must be capable of operating under hydraulic loadings and ranges of oil concentrations consistent with the performance of the oil harvesting device. It must be capable of producing output streams with the following characteristics:

(1) Oil - 10 percent water or less.

(2) Sorbent material - available for reuse or method for disposal.

(3) Water - 10 mg/l oil or less.

d. Oil Storage or Disposal

Specify floating or other appropriate land-based facilities which, in combination with on-board storage, will have capacity to store material to be collected from spills of at least one million gallons. Agglomerates must be processed before land disposal to preclude leaching. Other appropriate disposal techniques such as incineration will be considered as alternatives.

TABLE 20 (Concluded)

e. Vessel

The recovery system must be designed for either permanent or temporary mounting on appropriate existing vessels. The development of vessels designed specifically for oil recovery use will not be considered. Vessels to be used must be capable of speeds of at least 12 knots under the environmental conditions listed above (however, not performing the oil recovery function). They must accommodate any required oil-sorbent separation equipment, the oil recovery device and, operating personnel, 24-hour fuel supply and all oil specified for storage on board. They must be capable of speeds of at least 8 knots (however not performing an oil recovery function) in 10-foot seas and winds of up to 38 mph.

The system was designed to satisfy the required recovery rate of 10,000 GPH of bunker "C" at 20°C. The rationale for the selection of the system operating parameters such as sweep speed, sorbent coverage, and sorbent residence time are presented in Section V. Many elements of the unprotected water system are similar to those on the protected water system. These are not presented in detail again so that reference should be made to the appropriate parts of Section VI.

GENERAL DESCRIPTION

The basic sorbent recovery system consists of a pneumatic broadcasting system with a moving parallel-plate nozzle, a harvesting conveyor, a transfer conveyor, a sorbent regenerator, the necessary drive systems and a catamaran type platform. The basic characteristics of the unprotected water (10,000 GPH) Sorbent-Oil recovery system are presented in Table 21. Figure 18 is an overall arrangement drawing of this system. The recovery equipment is mounted on a specifically designed platform rather than a vessel of opportunity. The reasons for this form of mounting are presented in detail in Section V. Basically they are improved operating efficiency, reduced reaction time, and potentially lower life-cycle cost.

TABLE 21

Characteristics of Unprotected Water
Sorbent-Oil Recovered System

Design Oil Recovery Rate	10,000 gal/hr
Slick Thickness	1.5 mm
Sweep Speed	2.60 ft/sec
Sweep Width (Normal)	32.0 ft
Sweep Width (Extension Booms)	64.0 ft
Active Length	65.0 ft
Sorbent Material	Open cell polyurethane foam
Sorbent Form	Chips 3 in. × 3 in. × 1/4 in. normal
Sorbent Pore Size	
Oil Viscosity ≤ 1000 cps	80 PPI
Oil Viscosity > 1000 cps	30 PPI
Sorbent Residence Time	25 sec
Sorbent Coverage	75 percent

Oil Recovery Performance
1.5 mm Slick Thickness

Oil Viscosity cps	Oil Recovery Rate GPH	Oil Recovery from Slick percent	Water Recovery Rate GPH
≤ 6000	10,000	90	962
10000	9,450	35	844
20000	8,600	77.5	752

Oil Recovery for Viscosity ≤ 6000 cps

Slick Thickness mm	Normal Sweep Width (16 ft) GPH	With Extension Booms (64 ft) GPH
0.5	3300	6700
1.0	6700	13400
1.5	10000	20000

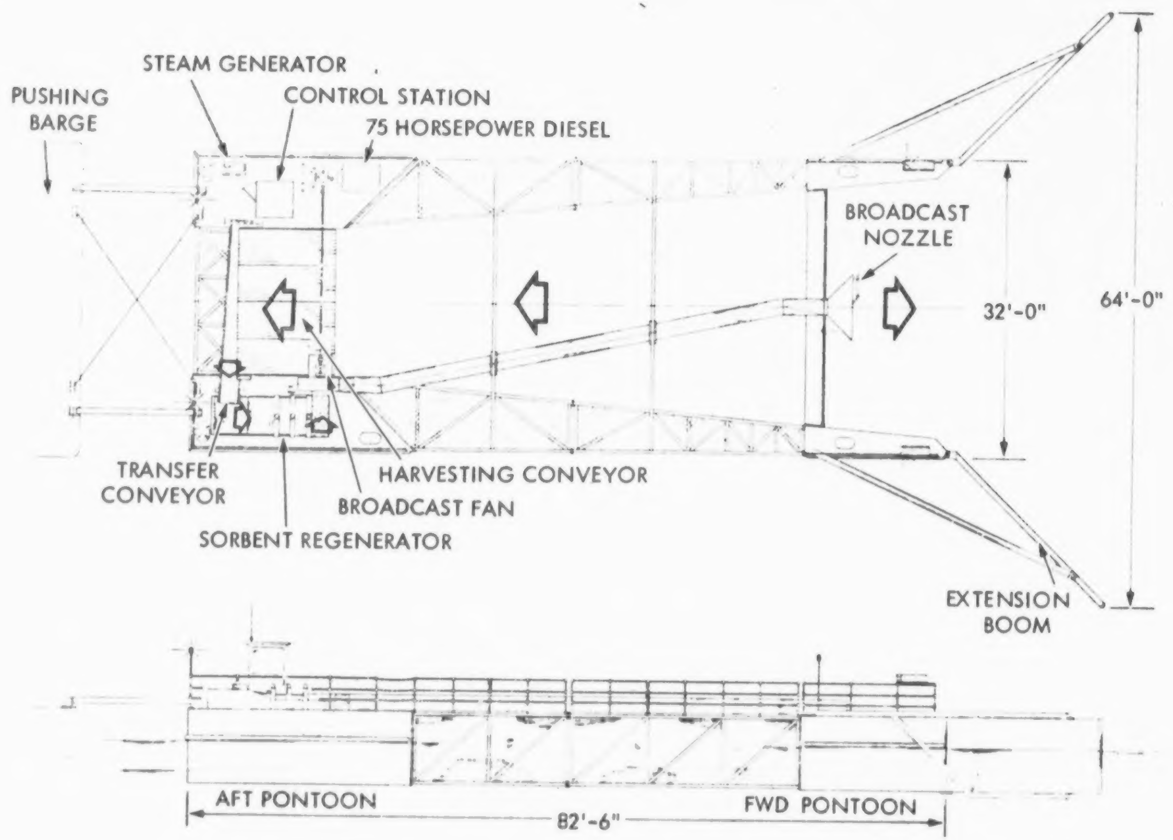
STEAM GENERATOR
PUSHING BARGE
CONTROL STATION
75 HORSEPOWER DIESEL
BROADCAST NOZZLE
32'-0"
64'-0"
TRANSFER CONVEYOR
HARVESTING CONVEYOR
BROADCAST FAN
SORBENT REGENERATOR
EXTENSION BOOM
AFT PONTOON
82'-6"
FWD PONTOON

FIGURE 18 - UNPROTECTED WATER RECOVERY SYSTEM ARRANGEMENT DRAWING

RECOVERY SYSTEM COMPONENTS: BROADCASTING SYSTEM

The broadcasting system uses larger components but is otherwise similar in concept to the system on the protected water unit. Its technical and performance characteristics are presented in Table 22.

TABLE 22

Broadcasting System Characteristics

Sorbent Form	Chips 3 in. × 3 in.× 1/4 in. nominal
Sorbent Broadcasting Rate	1.3 ft^3/sec 1010 chips/sec
Regenerated Sorbent Density	6.0 lbs/ft^3
Broadcasting Nozzle Type	Moving Parallel Plate
Nozzle Rate	0.5 cycle/sec
Nozzle Angle	±50 degrees
Nozzle Drive	Air Cylinder
Broadcasting Duct Diameter	21 in.
Broadcasting Duct Length	48.0 ft
Air Speed	45 ft/sec
Fan Type	American Blower Series 106 Industrial Fan Size 21 Long Shavings Wheel
Diameter (Wheel)	36.5 in.
RPM	1099
Fan Power (Total)	36 HP
Transmission	Mechanical
Total Sorbent in System	56 ft^3 44,000 Chips

Sorbent Loss Rate

Wind Speed mph	Loss Rate ft^3/hr
0 - 10	9.4
10 - 20	47.2
20 - 30	93.7

Harvesting and Transfer Conveyors

The harvesting conveyor is mounted between the aft pontoons of the recovery platform. The overall width is 16 ft which is made up of four 4-ft wide belts. Each of these belts is supported on its edges and centerline by a support frame which also carries the sprocket shaft. The length between sprocket shafts is 14 ft. The hydraulic drive system can provide in excess of 300 ft-lbs of torque at 74 RPM. This is sufficient to lift a combined weight of chips and debris of about 800 pounds. The technical characteristics of the harvesting conveyor are presented in Table 23.

TABLE 23

Harvesting Conveyor Characteristics

Conveyor Width	Total 16.0 ft (4 sections 4.0 ft)
Conveyor Angle	45 deg.
Conveyor Length	14.0 ft
Linear Belt Speed	2.6 ft/sec
Belt Material	1 in. by 1 in. mesh extra heavy duty (button head weld) flat-wire belt galvanized steel construction
Belt Drive	32 Class C Sprockets 8.25 in. diameter 23 teeth
Power	4 HP
Transmission	Hydraulic
Conveyor Support	Integral Support Frame

The transfer conveyor is similar to the one used in the protected water system except for a greater belt width and speed. Its characteristics are given in Table 24.

TABLE 24

Transfer Conveyor Characteristics

Conveyor Belt Width	3.0 ft
Conveyor Length	20.0 ft
Linear Belt Speed	2.5 ft/sec
Belt Material	3-Ply Stitched canvas Neoprene covered
Conveyor Support	Troughed Bed* with integral takeup and drive pulley
Drive	8 in. diameter pulley-friction drive
Power	1 HP
Transmission	Hydraulic

* Hytrol Conveyor Company Model "TR" Horizontal Belt Conveyor or Equivalent

Sorbent Regenerator

The operating principles and basic configuration of the sorbent regenerator for the unprotected water unit are identical to the protected water unit. These items are discussed in detail in Section VI. The belt width for the unprotected water unit regenerator is 60 inches compared with 24 inches for the protected water unit. To limit the increase in belt width in the unprotected water unit, the unit sorbent loading was increased from 0.22 ft^3/ft^2 to 0.3 ft^3/ft^2. This slightly increases the density of the regenerated sorbent but it remains at an acceptable value. The development program reported in Appendix D covered values in excess of 0.3 ft^3/ft^2 unit sorbent loading without difficulties. Table 25 presents the characteristics of the resulting unit.

TABLE 25

Sorbent Regenerator Characteristics

Design Sorbent Rate	1.3 ft^3/sec
Belt Speed	1.0 ft/sec
Maximum Squeezing Force	220 lb/in of belt-width
Number of Squeezing Stations	3
Squeezing Roller Width	60 inches
Squeezing Roller Diameter	6 inches
Lower Belt Material	Steel Balanced Belting Type B-60-32-4
Upper Belt Material	Reinforced Neoprene
Power	4 HP
Transmission	Hydraulic Drive
Air Supply	Engine Driven Compressor
Squeezing Force	Air Cylinder
Squeezing Roller Travel	4 in.
Heating	Heating Coils in Collecting Pan 3000 lb/hr steam

Sorbent Regeneration Performance

Oil Viscosity cps	Sorbent PPI	Squeezing Force lb/in	Regenerated Sorbent Density - lb/ft^3
2	80	220	5.0
300	80	220	6.0
1000	30	220	5.5
4500	30	220	6.0
20000	30	220	8.0

Miscellaneous Equipment

Additional components which should be included with the recovery system are an oil transfer pump with a capacity of 500 GPM at 40 ft of head and a steam generator capable of evaporating 360 gal/hr at 120 psi.

Power and Transmissions

The recovery system components are powered by a diesel engine driving through a hydraulic or combination hydraulic and mechanical transmission system. The basic concept of the power train is identical with that on the protected water unit. For this case, the engine is a 75 HP radiator-cooled Model 3-53N Detroit Diesel or equal. The broadcasting system fan and the oil transfer and bilge pump can be driven either by a direct mechanical or hydraulic system. The mechanical and hydraulic transmissions for the 10,000 GPH systems are shown schematically in Figures 19 and 20, respectively. The mechanical system can be made to satisfy the arrangement requirements and thus is recommended because of its lower cost. The sorbent regenerator, the harvesting conveyor and the transfer conveyor require a hydraulic transmission which is shown schematically in Figure 21.

RECOVERY PLATFORM

The recovery platform is based on a catamaran concept with hulls consisting of four pontoons joined by trusses. The side trusses are screened to confine the sorbent material and the aft pontoons are configured to herd the sorbent to the harvesting conveyor. The harvesting conveyor is mounted between the aft pontoons. Figure 18 presents an overall arrangement of the recovery system equipment and platform. The basic characteristics of the recovery platforms are presented in Table 26.

Hull

The hull configuration of pontoons joined by trusses was selected for the following reason:

- Simpler to disassemble into units suitable for over road transport,
- Lower weight than conventional catamarans hulls,
- Satisfactory motions in the design sea conditions.

Appendix E presents the results of a 1/4-scale model test of this platform concept. These tests covered, sorbent broadcast and recovery in calm water and waves, motions in waves, and towing stability and resistance.

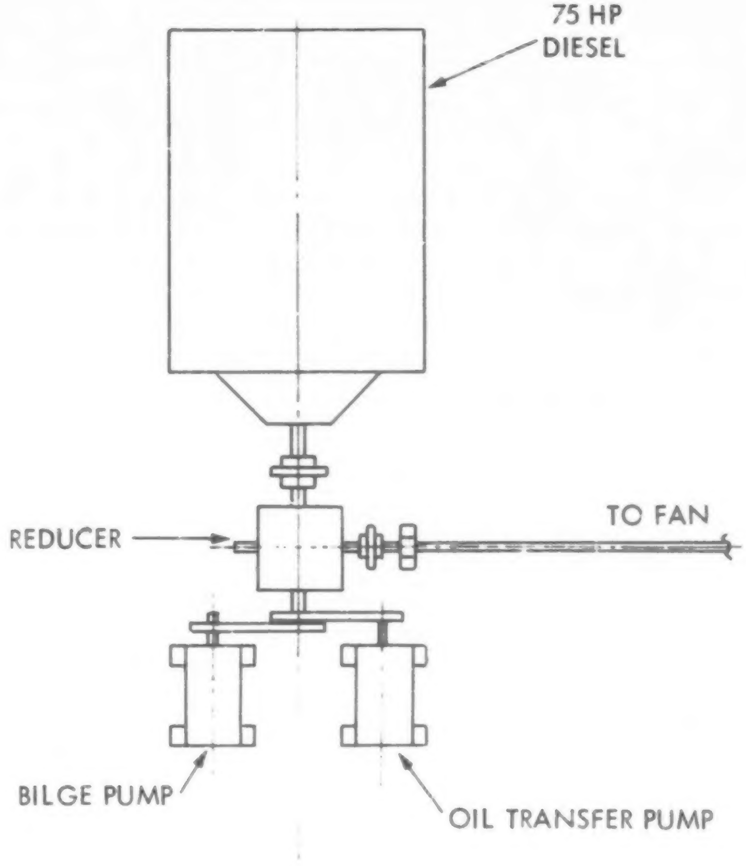
75 HP
DIESEL
REDUCER
TO FAN
BILGE PUMP
OIL TRANSFER PUMP

FIGURE 19 - DIAGRAM OF FAN AND PUMP MECHANICAL TRANSMISSION FOR 10,000 GPH SYSTEM

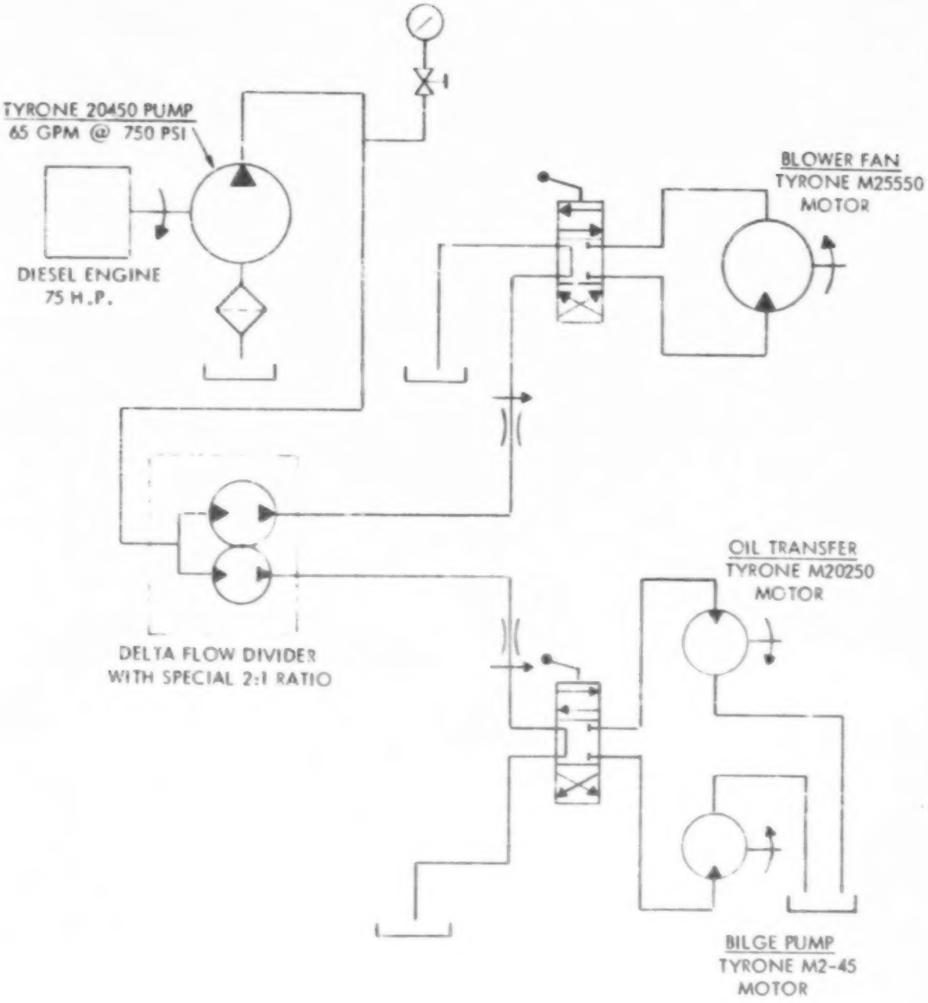
TYRONE 20450 PUMP
65 GPM @ 750 PSI
DIESEL ENGINE
75 H.P.
BLOWER FAN
TYRONE M25550
MOTOR
DELTA FLOW DIVIDER
WITH SPECIAL 2:1 RATIO
OIL TRANSFER
TYRONE M20250
MOTOR
BILGE PUMP
TYRONE M2-45
MOTOR

FIGURE 20 - SCHEMATIC DIAGRAM OF FAN AND PUMP HYDRAULIC TRANSMISSION FOR 10,000 GPH SYSTEM

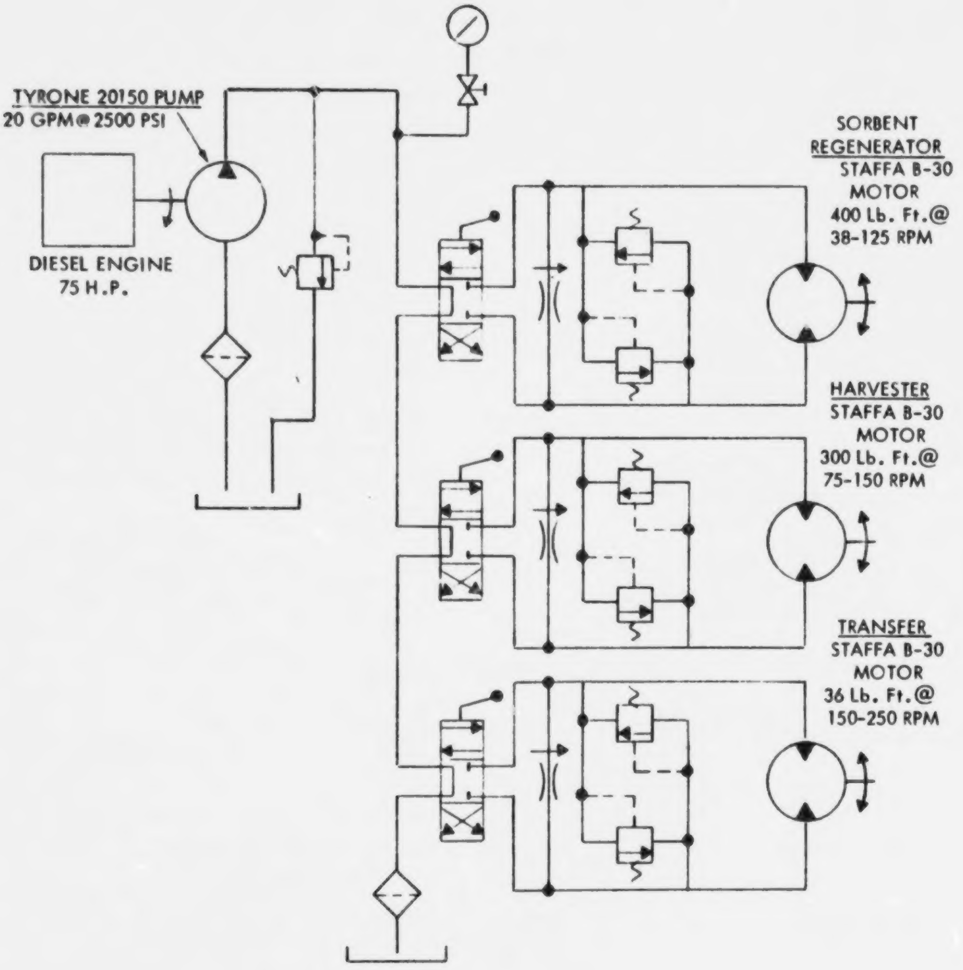
TYRONE 20150 PUMP
20 GPM@2500 PSI
DIESEL ENGINE
75 H.P.
SORBENT
REGENERATOR
STAFFA B-30
MOTOR
400 Lb. Ft.@
38-125 RPM
HARVESTER
STAFFA B-30
MOTOR
300 Lb. Ft.@
75-150 RPM
TRANSFER
STAFFA B-30
MOTOR
36 Lb. Ft.@
150-250 RPM

FIGURE 21 - SCHEMATIC DIAGRAM OF SORBENT REGENERATOR AND CONVEYOR HYDRAULIC TRANSMISSION FOR 10,000 GPH SYSTEM

TABLE 26

Unprotected Water System Platform Characteristics

Platform Concept	Catamaran
Overall Length	82.0 ft
Overall Beam (Normal)	32.67 ft
Overall Beam (Extension Booms)	64.0 ft
Draft (Maximum)	4.5 ft
Hull Beam (Maximum)	3.5 ft
Hull Depth	8.5 ft
Hull Structure	Aluminum
Light Ship Weight	29,065 lbs
Service Loads	2360 lbs
Recovered Fluid (10,000 gals)	75,000 lbs
Full Load Condition	106,425 lbs
Deployment Draft	1.25 ft
Full Load Draft	4.5 ft
Propulsion	-
Deployment Speed	10 knots
Onboard Chip Storage	500 ft^3

Shipping Characteristics

Item	Length ft	Width ft	Height ft	Weight lbs
Aft Pontoon	24.0	8.5	8.5	3950 (each of 2)
Fwd Pontoon	12.0	3.5	8.5	1400 (each of 2)
Fwd Beam	27.0	2.08	2.0	1420
Side Beams	27.0	8.0	8.0	1250 (largest of 4)
Aft Beams	16.0	7.0	7.5	1200 lbs

The hull and truss structure can be either aluminum or steel. Aluminum has a lower weight for greater onboard oil storage and easier shipping. A steel hull will have a lower initial cost and higher weight. The characteristics presented in Table 26 are based on aluminum construction. The recovery platform can be fitted with extension booms to increase the sweep width thus increasing oil recovery rate in thin slicks. Typical extension booms are shown in Figure 18. It is expected that these booms could be used only in relatively calm water.

Propulsion

The unprotected water recovery system is not self propelled. It may be either towed or pushed by a vessel of opportunity or a barge. Figure 18 illustrates how the system can be pushed by a barge. The recovered oil can then be pumped directly into the barge.

Outfit

In order to make the recovery platform an operational system, a certain amount of outfit is required. The typical outfit items are listed in Table 27.

TABLE 27

Unprotected Water System Outfit Items

Railings
Hatches
Anchors and Lines
Fenders
Fire Extinguishers
Lights
Lockers
Chocks and cleats
Piping
Radio
Chemical Toilet
Operators Stand
Miscellaneous

Weight Summary

A detailed weight estimate was prepared for the unprotected water recovery system and is presented in Table 28. This weight estimate is based on aluminum construction. If steel structures were used, the total structural weight would increase to about 45,500 pounds. This would reduce the amount of recovered oil which could be carried on a draft of 4.5 ft to about 6400 gallons.

TABLE 28

Weight Estimate for 10,000 GPH Unprotected
Water Sorbent-Oil Recovery System

CALCULATION OF WEIGHT

1 of 5

SHIP Unprotected Water Recovery Unit	WEIGHT IN	ABOVE MLD BASE LINE		REFERRED TO: Transom			
ITEM Structure - Aluminum	Pounds	C.G.	VERT. MOM.	C.G.	FWD MOMENTS	C.G.	AFTER MOMENTS
Aft Pontoons							
0.25 in. plate and							
[illegible] in. [illegible] in. x .25 in. angle on 15 in.							
centers.							
Outboard Sides	1721			12.[illegible]			
Inboard Sides	1152			[illegible]			
Transom	574			[illegible]			
Bow Plate	314			[illegible]			
Deck and Bottom	1446			[illegible].1			
Bulkheads	477			11.[illegible]			
Longitudinal webs	[illegible]			[illegible]			
Forward							
Pontoons							
Outboard sides	792			[illegible].5			
Inboard sides	643			75.[illegible]			
Bow	202			81			
Aft End	202			71			
Deck and Bottom	91			76			
Bulkheads	173			76			
Longitudinal webs	105			76			
	5907						

DATE | COMPUTED | CHECKED | BOTH SIDES

TABLE 28 (Continued)

CALCULATION OF WEIGHT

2 of 5

SHIP Open Water	WEIGHT IN	ABOVE MLD BASE LINE		REFERRED TO: Transom			
ITEM	pounds	C.G.	VERT. MOM.	C.G.	FWD MOMENTS	C.G.	AFTER MOMENTS
Forward Beam	1148			72			
Side Beams							
Upper Longitudinal Tubes	48			45.5			
Lower Tubes	457			45.5			
Vertical and Transverse Struts							
2 x 4 x 7	175			47			
2 x 4 x 5	202			47			
2 x 7 x 4	176			47			
Diagonals 2 x 5 x 11	347			47			
2 x 5 x 12	373			47			
2 x 7 x 5	353			47			
Aft Beam							
3 x 16	240			2.0			
4 x 5 x 4 x 7	151			2.0			
2 x 6 x 5 x [illegible] x 8	321			2.0			
Grating Aft 15 x 6	250			2.0			
Sides 2 x 51 x 5	1377			43.0			
Sub Total	15220			34.5	525324		
Margin 20 percent	3044						
Total Structure	18264			34.5	630350		

DATE | COMPUTED | CHECKED

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TABLE 28 (Continued)

CALCULATION OF WEIGHT

3 of 5

SHIP Open Water ITEM Mechanical Systems	WEIGHT IN pounds	ABOVE MLD BASE LINE		REFERRED TO: Transom			
		C.G.	VERT. MOM.	C.G.	FWD MOMENTS	C.G.	AFTER MOMENTS
	8000			8.5	68,000		
Hull Outfit and Equipment							
Railing	340			16			
Hatches	240			15			
Anchors and Line	150			70			
Fenders	200			41			
Fire Extinguishers	200			30			
Lights	50			70			
Lockers	50			16			
Chocks and Cleats	75			10			
Miscellaneous	100			30			
Piping	250			10			
Radio	30			20			
Chemical Toilet	50			30			
Operators Stand.	450			60			
Sub-Total	2325			27.3	63400		
Margin 20 percent	475						
Total Hull Outfit	2800			27.3	76050		
DATE	COMPUTOR	CHECKER				BOTH SIDES	

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TABLE 55 (Continued)

CALCULATION OF WEIGHT

4 of 5

SHIP Open Water

ITEM Loads

ITEM	WEIGHT IN pounds	ABOVE MLD BASE LINE C.G.	ABOVE MLD BASE LINE VERT. MOM.	REFERRED TO: Transom C.G.	FWD MOMENTS	C.G.	AFTER MOMENTS
Diesel Fuel	400			10	4000		
Personnel an [illegible]	700			10	7000		
Sorbent	1200			10	12000		
Water	160			10	1600		
Total	[illegible]			10	[illegible]		

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TABLE [illegible] (Concluded)

CALCULATION OF WEIGHT

5 of 5

SHIP Open Water	WEIGHT IN	ABOVE MLD BASE LINE		REFERRED TO [illegible]			
ITEM Summary	POUNDS	C.G.	VERT. MOM.	C.G.	FWD MOMENTS	C.G.	AFTER MOMENTS
Structure - Aluminum	[illegible]			[illegible]	[illegible]		
Mechanical Systems	[illegible]			[illegible]	[illegible]		
Outfit	[illegible]			[illegible]	[illegible]		
Light Ship	[illegible]			[illegible]	[illegible]		
Loads	[illegible]			[illegible]	[illegible]		
Service Condition	[illegible]			[illegible]	[illegible]		
Recovered Oil	[illegible]			[illegible]	[illegible]		
Full Load (Draft - [illegible] ft [illegible] in.	[illegible]			[illegible]	[illegible]		

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CREW AND OPERATING PROCEDURES

The unprotected water sorbent-oil recovery system should be operated by a four man crew consisting of a captain, engineer and two deck hands. The duties of these crew members are similar to those assigned to the crew of the protected water system which are detailed in Section VI. The operating procedures for the unprotected water system are similar to those for the protected water system. The major difference is that the unprotected water system is not self propelled. It can be either towed or pushed by a vessel of opportunity. A particularly favorable procedure would be to have the recovery system pushed by a tank barge. The recovered oil could then be pumped directly to the barge, as mentioned previously.

COST ANALYSIS

An analysis was made of the construction and operating costs of the 10,000 GPH unprotected water recovery system. The assumptions and methods used in this analysis are identical to those used for the protected water system and are presented in detail in Section VI.

The construction cost will depend on the structural material and the extent of the outfit. The selection of these items depends on the intended duty and the importance of initial cost. The construction cost data are thus presented in Table 29 for the various system elements. Various possible cost options are presented in Table 30 ranging from minimum initial cost to the complete system. The recovery machinery is common to all cases and is the heart of the system. As a result, a detailed analysis of the recovery machinery construction cost estimate is given in Table 31.

The direct operating costs were estimated on a per hour of effective oil recovery basis and are presented in Table 32. The charter rates for the tugboat and barge, if used, are subject to wide variations depending on the exact situation.

TABLE 29

Unprotected Water Recovery System
Cost Analysis

Summary	Dollar Total for 1			Dollar Total ea. of 3		
	Materials	MH	Total	Material	MH	Total
Recovery Unit - Installed and operating						
Combined mechanical and Hydraulic	20000.	[illegible]	28000.	17,660.	585.	24,680.
Full Hydraulic Drive	22400.	670.	30500.	18,770.	589.	26,840.
Hull - Steel	20700.	-	20700.	18,630.	-	18,630.
- Steel with inorganic zinc coating	26500.	-	26500.	23,850.	-	23,850.
- Aluminum	49700.	-	49700.	44,730.	-	44,730.
Outfit - Minimum - Steel	3850.	382	8430.	3390.	336	7420.
- Aluminum	4150.	382	8730.	3650.	336	7680.
- Complete - Steel	12300.	458	17780.	10,810.	394	15,540.
- Aluminum	17040.	458	21740.	15,000.	394	19,730.
Supply of Sorbent Material	4600.	-	4600.	4600.	-	4600.

TABLE 30

Unprotected Water Recovery System
Total Construction Costs

	Dollar Total for 1	Dollar Total each of 3
Minimum Initial Cost		
Recovery Unit - combined mechanical and Hydraulic	28060.	24680.
Steel Hull	20700.	18630.
Outfit (Minimum)	8430.	7420.
Total w/o Sorbent Material	57190.	50730.
Supply of Sorbent Material	4600.	4600.
Total with Sorbent Material	61790.	55330.
Continuous Duty		
Recovery Unit - Combined Mechanical and Hydraulic	28060.	24680.
Aluminum Hull	49700.	44730.
Outfit (Complete)	21760.	19730.
Total w/o Sorbent Material	99520.	89140.
Supply of Sorbent Material	4600.	4600.
Total with Sorbent Material	104120.	93740.

TABLE 31

Unprotected Water Recovery Unit
Recovery Machinery Cost

Oil Recovery Machinery	Dollar Total for 1	Man Hours
Sorbent Regenerator	5242.	315
Fan	1000.	-
Harvesting Conveyor	2800.	150
Broadcast Duct	750.	-
Broadcast Nozzle	100.	24
Transfer Conveyor	1600.	16
Hydraulic Drive	4920.	88
Mechanical Drive	800.	12
Diesel	2720.	40
Transfer Pump	130.	-
Total for 1	20,000	330
Total each of 3 at .88	17,655	290
Added for full hydraulic drive	2400	60
Total for 1	22,462	390
Total each of 3 at .88	19,767	343
Installation and Debug system		
(Hydraulic and Mechanical)		
Total for 1	-	336
Total each of 3 at .88	-	295
(Full hydraulic system)		
Total for 1	-	280
Total for each of 3 at .88	-	246
Total Labor to Fabricate and Install		
(Hydraulic and Mechanical Drive)		
Total for 1	-	666
Total each of 3	-	585
(Full Hydraulic System)		
Total for 1	-	670
Total each of 3	-	589

TABLE 32

Unprotected Water Recovery System Direct Operating Costs

Per Hour of Effective Oil Recovery[1]	
Crew	$40.00
Maintenance	10.00
Sorbent	435.00
Fuel and Miscellaneous	10.00
Tug Boat	62.50
Barge	20.00
Total	$577.50
70 Percent Lost Sorbent Recovery on Second Sweep[2]	
Crew	$80.00
Maintenance	20.00
Sorbent	130.50
Fuel and Miscellaneous	15.00
Tugboat	125.00
Barge	20.00
Total	$390.50

[1] No attempt is made to recover sorbent material lost due to winds.

[2] A second sweep of the slick area is made with the broadcasting system off to recover sorbent material. It is assumed that 70 percent of the sorbent which was lost is recovered by this procedure.

SECTION VIII

ACKNOWLEDGMENTS

This project was carried out by a team of HYDRONAUTICS, Incorporated personnel headed by Mr. E. R. Miller, Jr. and Dr. A. Gollan and including Mr. L. Stephens, Mr. J. Ricklis, Mr. H. Lain and Mr. H. Cartright. Mr. W. Lindenmuth also contributed to the development of the initial concept. Mr. K. Jakobson acted as the project officer for the Environmental Protection Agency.

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SECTION IX

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1. Witmer, Dr. F. E., and Gollan, Dr. A., "Final Report of Phase 1 Development Program of a Continuous Regenerating Moving Bed to Remove Oil from Oil-Water Suspensions," HYDRONAUTICS, Incorporated Technical Report 7080-1 (in preparation).

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SECTION X

APPENDICES

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APPENDIX A

CHARACTERIZATION OF THE SORBENT MATERIAL

The objective of this task was to generate data on the oil absorption capabilities of the sorbent material as a function of sorbent characteristics, oil characteristics, slick thickness and residence time on the slick. The sorbent material selected for use in the oil sorbent recovery system was open-cell reticulated polyurethane foam made by the Scott Paper Company.

The data were obtained from the tests of almost 900 individually tested polyurethane chips. Test conditions included the following parameters:

Slick thickness	0.5 mm - 3.5 mm
Slick temperature	4 - 27°C
Matrix porosity	30, 60, 80, 100, (Mostly 30 and 80 ppi)
Matrix reusability	Fresh and regenerated (Mostly regenerated)
Media geometry	Square and rectangular
Residence times of media in slick	0 - 60 sec (Mostly 5, 10, 15, 30 sec)
Four types of oils:	Diesel, No. 4, Crude, Bunker "C"

The first tests were scouting tests, after which the tests where standardized in the following way. Only regenerated sorbent material was used since this represents the real case. The scouting tests revealed that there were no differences in absorption rates or absorbed quantities between fresh and regenerated polyurethane chips. According to data reported in Reference 1, absorption of heavy oils proceeded at a lower rate in the 100 ppi grade, then in the smaller ppi grades, while the lighter oils did not indicate a basic change between 100 and 80 ppi. For this reason tests were carried out on 80 and 30 ppi grades only.

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Although a range of residence times of the chips on the oil slick between 0 and 60 seconds were considered for testing, it was decided after the scouting tests that enough oil would be absorbed into the chip in periods shorter than 60 seconds to justify a reduction in absorption time. Therefore, tests were conducted with absorption times of 5, 10, 15 and 30 seconds. Drain time was fixed at 10 seconds, which was the estimated elapsed time between lifting the chip out of the slick and regenerating it.

Each combination of variables was checked by three different chips. Average results obtained from sets of three chips were used for calculating absorption. A standard measure of absorption was utilized throughout the tests; i.e., absorption ratio. This is the ratio, expressed in percent, of the weight of oil absorbed by a certain chip, to the weight of the oil directly underneath this chip. These data are best presented by plotting the absorption ratio as a function of the oil viscosity, using slick thickness, and absorption times as parameters. Viscosities and specific gravities of the oils used, were measured within the range of 1-30°C.

Figure 22 presents viscosity data for the four types of oils, as determined by England Laboratories of Beltsville, Maryland. Figure 23 presents specific gravity data as determined in the laboratory at HYDRONAUTICS, Incorporated.

The data are presented in Figures 24 through 30. It was found to be very difficult and time-consuming to produce an oil slick having an exact selected thickness. Thus, the data, which were distributed throughout the thickness range, have arbitrarily been divided into three groups: 0-1; 1-2; 2-3.5 mm. Data from each group were plotted separately using absorption time as the parameter. Figures 24 through 26 present data for 30 ppi grade polyurethane foam and Figures 27 through 29 present data for 80 ppi grade. Figure 30 is an example of the data for one specific absorption time - 15 seconds. Although the data show some scatter, there still is an unmistakable trend which indicates less viscous oils, (Crude, No. 4 and diesel) are absorbed much better than the viscous Bunker "C" oil. Also the curves indicate that the absorption ratios are improved as absorption times are increased. It was noticed that more oil, especially in the lighter oils group, was lost during the drain period from the 80 ppi grade. This phenomenon is shown in Figure 26,

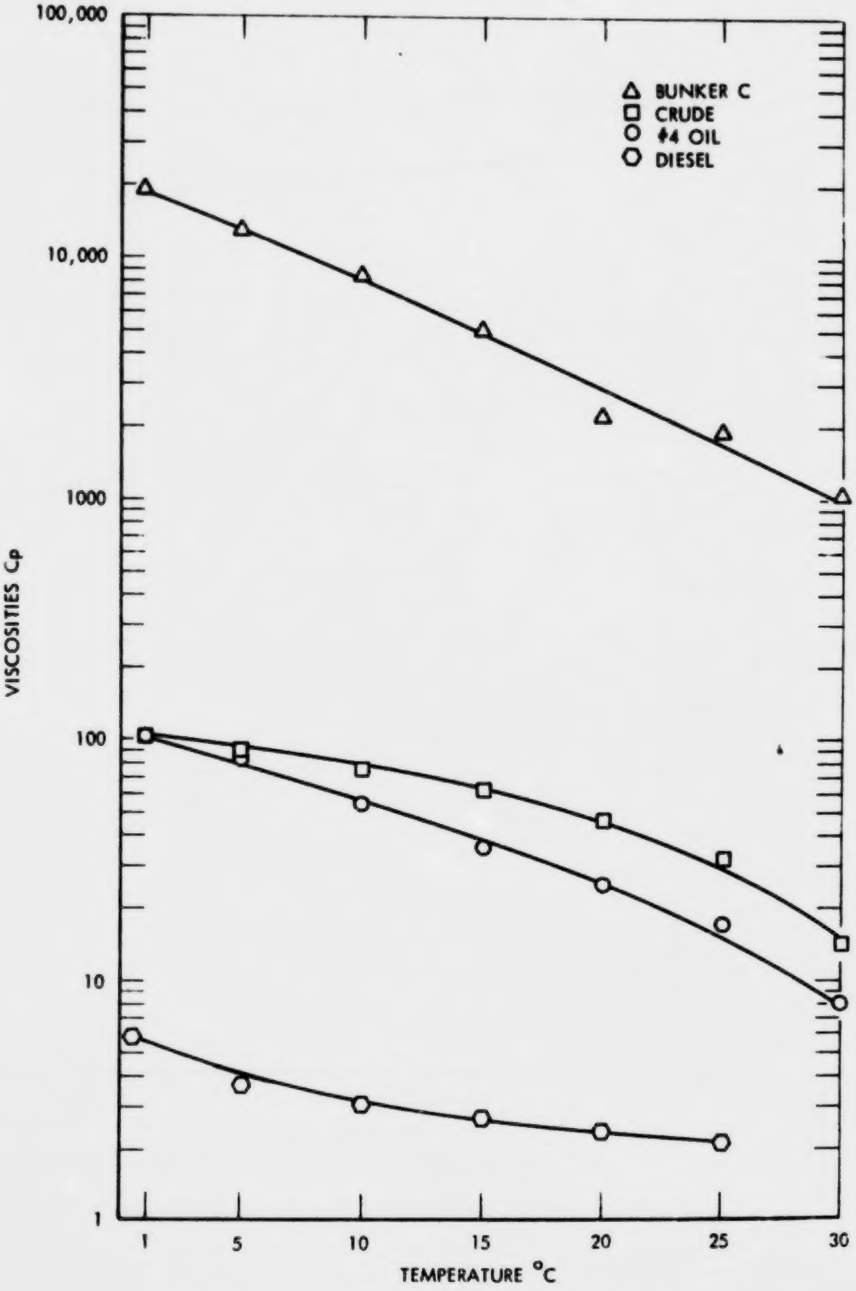


FIGURE 22 - VISCOSITIES OF OILS AS A FUNCTION OF TEMPERATURE

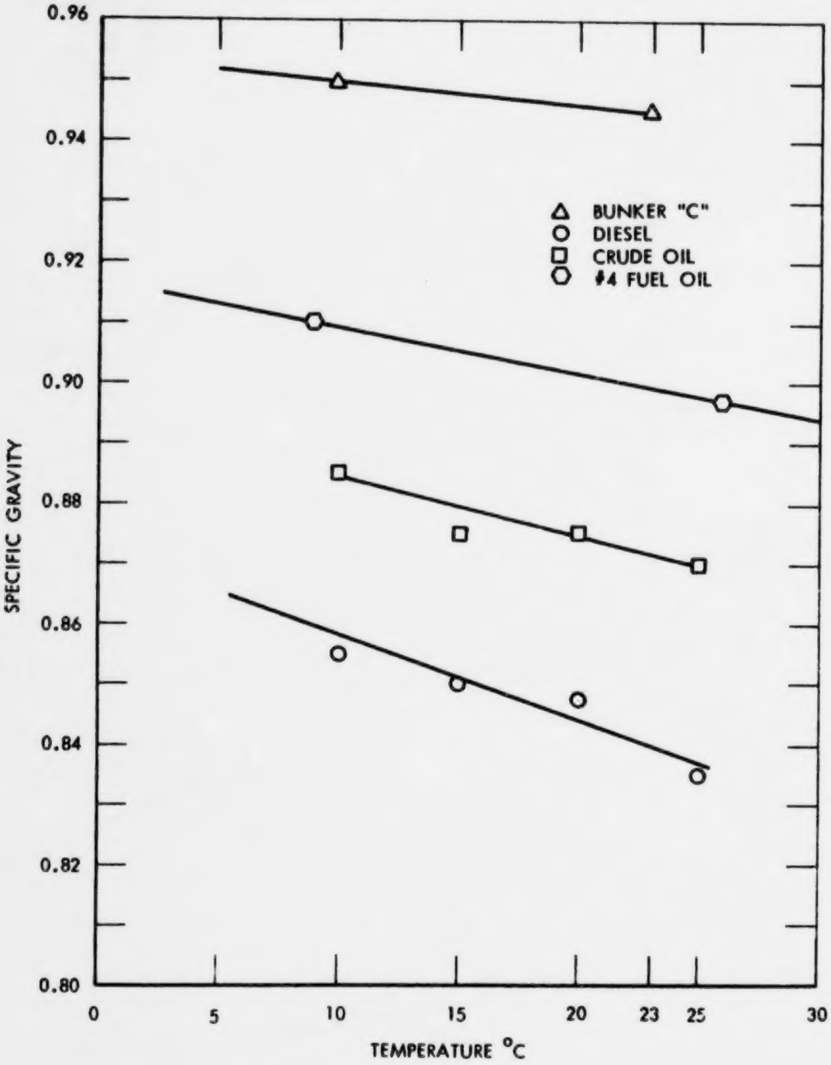


FIGURE 23 - SPECIFIC GRAVITIES OF OILS AS A FUNCTION OF TEMPERATURE

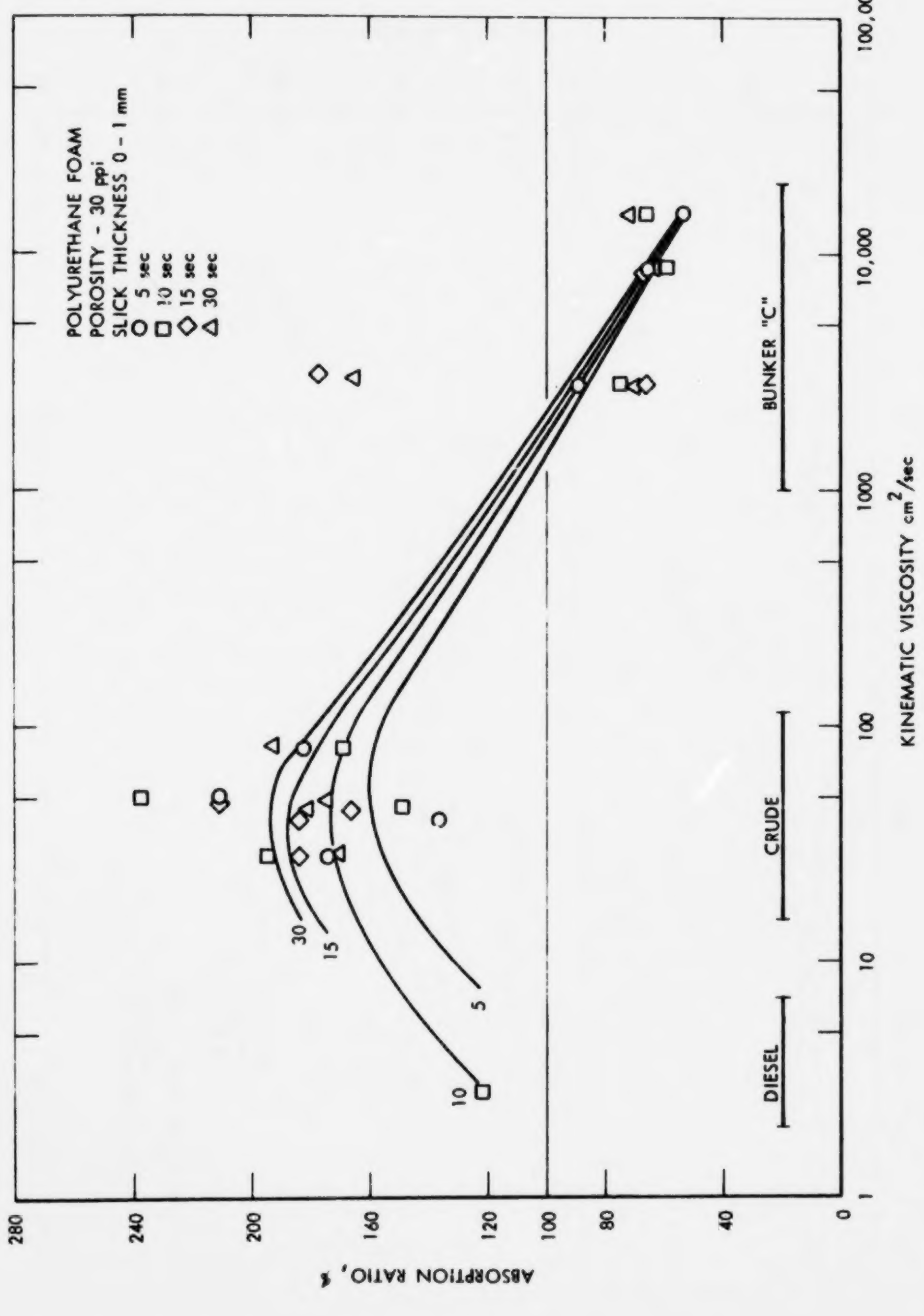


FIGURE 24 - EFFECT OF VISCOSITY AND RESIDENCE TIME ON OIL ABSORPTION

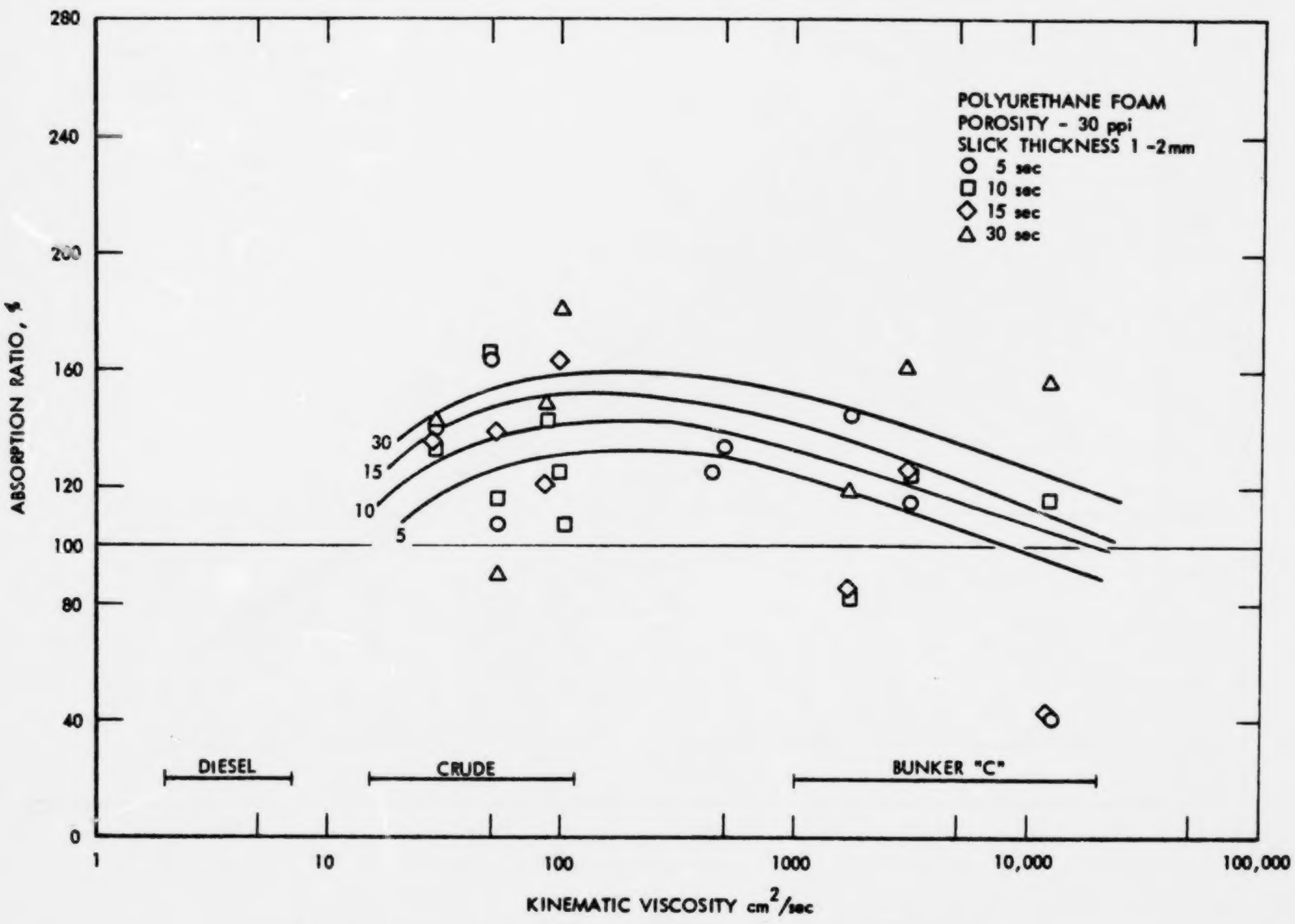


FIGURE 25 - EFFECT OF VISCOSITY AND RESIDENCE TIME ON OIL ABSORPTION

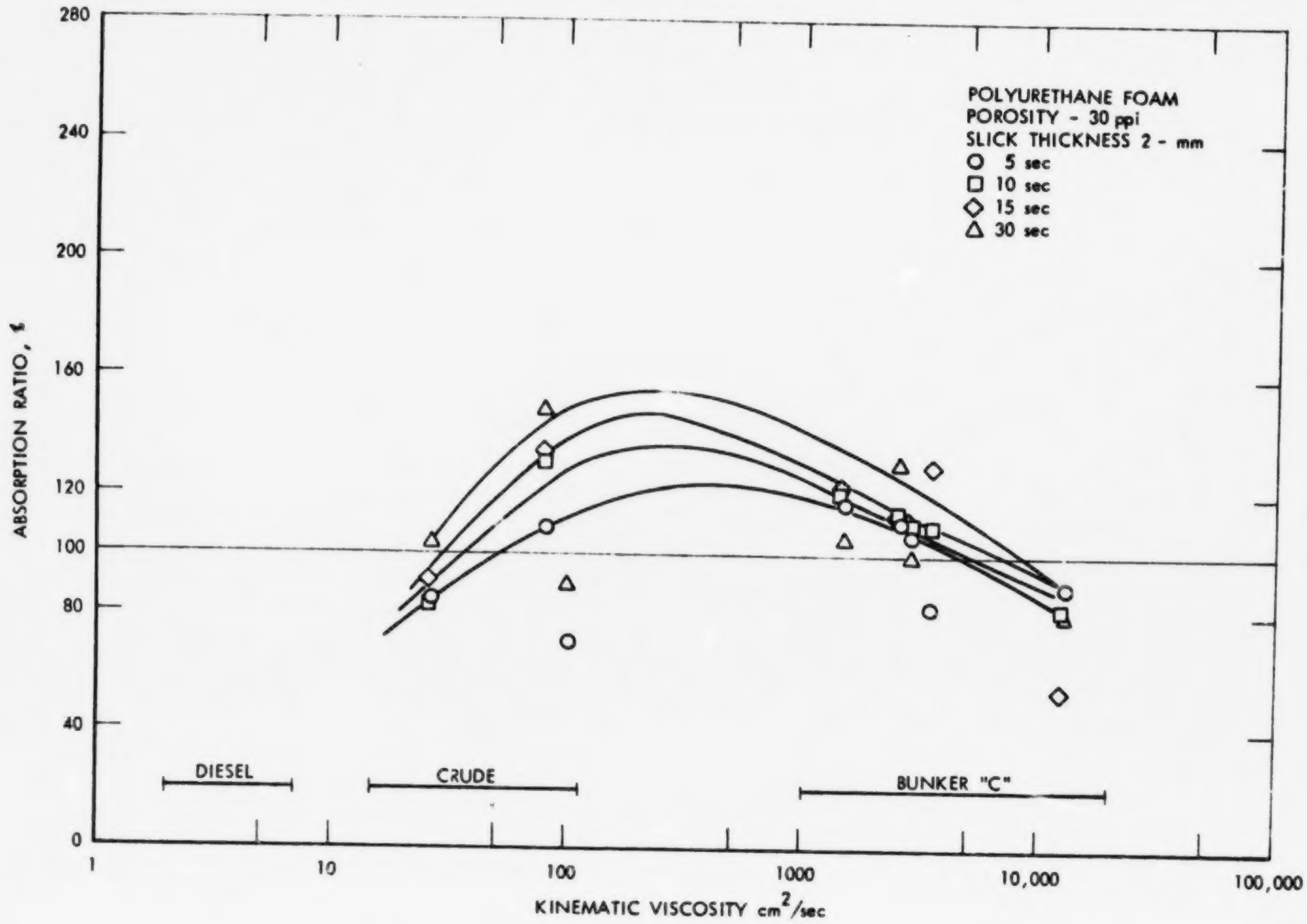


FIGURE 26 - EFFECT OF VISCOSITY AND RESIDENCE TIME ON OIL ABSORPTION

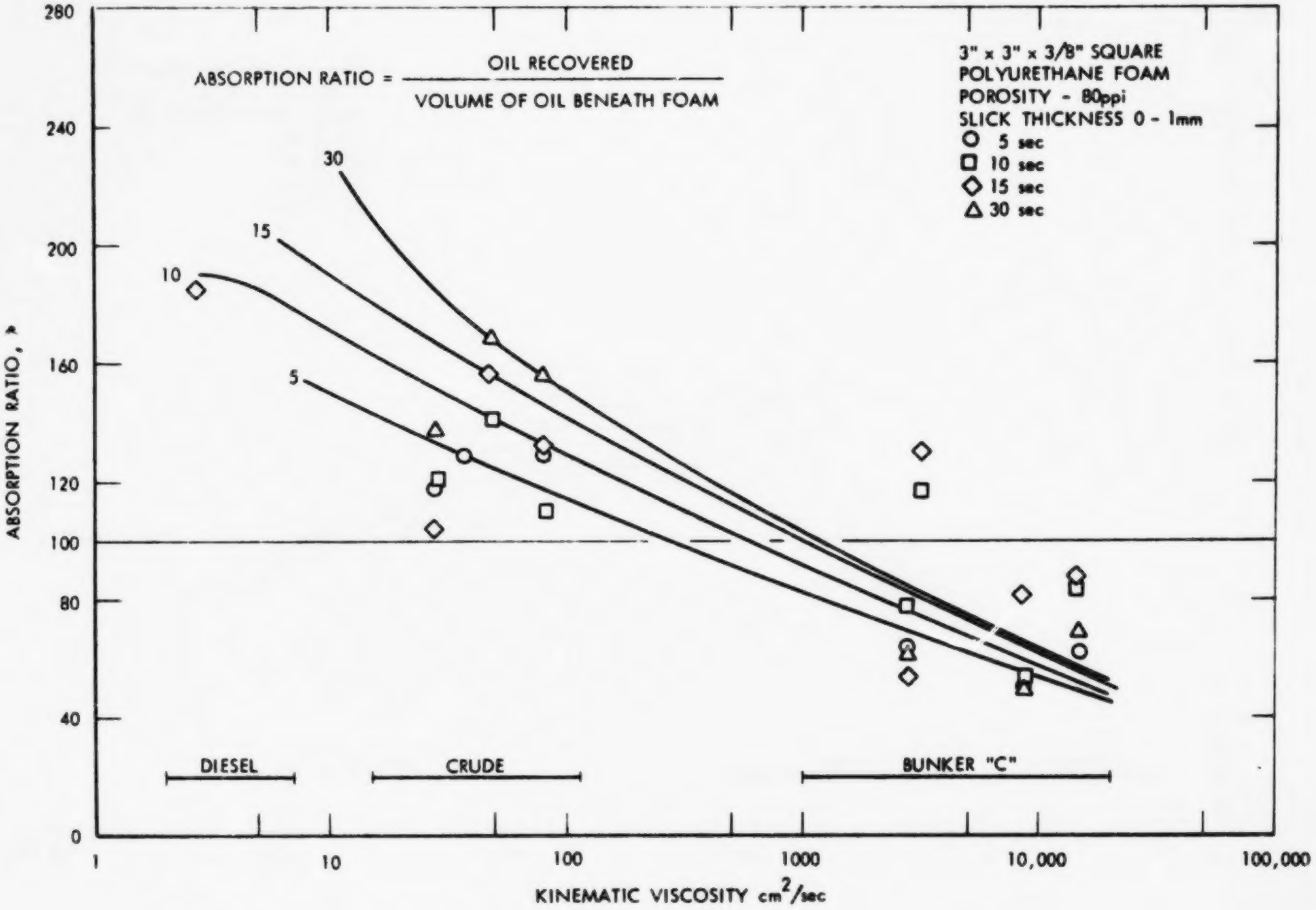


FIGURE 27 - EFFECT OF VISCOSITY AND RESIDENCE TIME ON OIL ABSORPTION

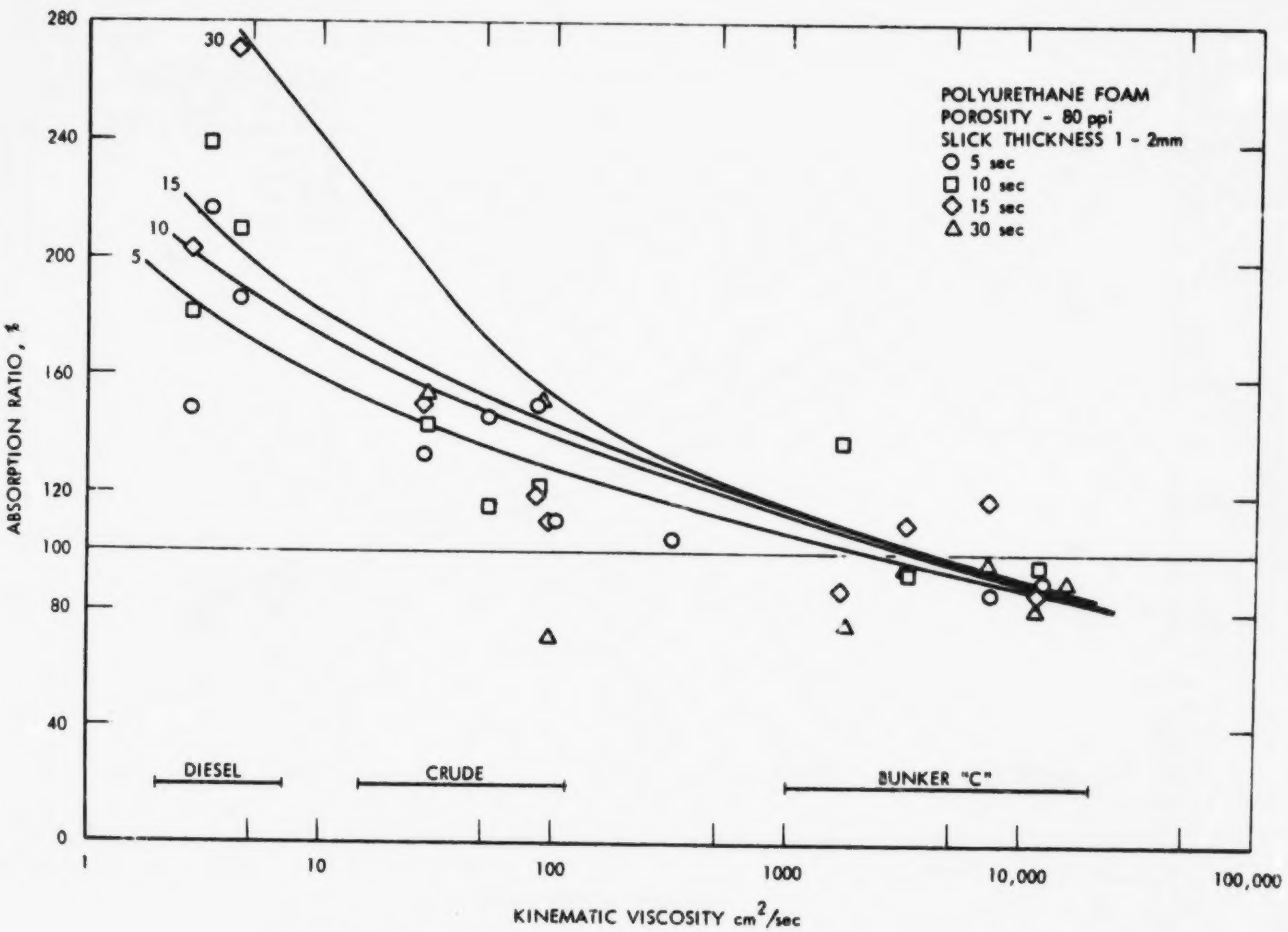


FIGURE 28 - EFFECT OF VISCOSITY AND RESIDENCE TIME ON OIL ABSORPTION

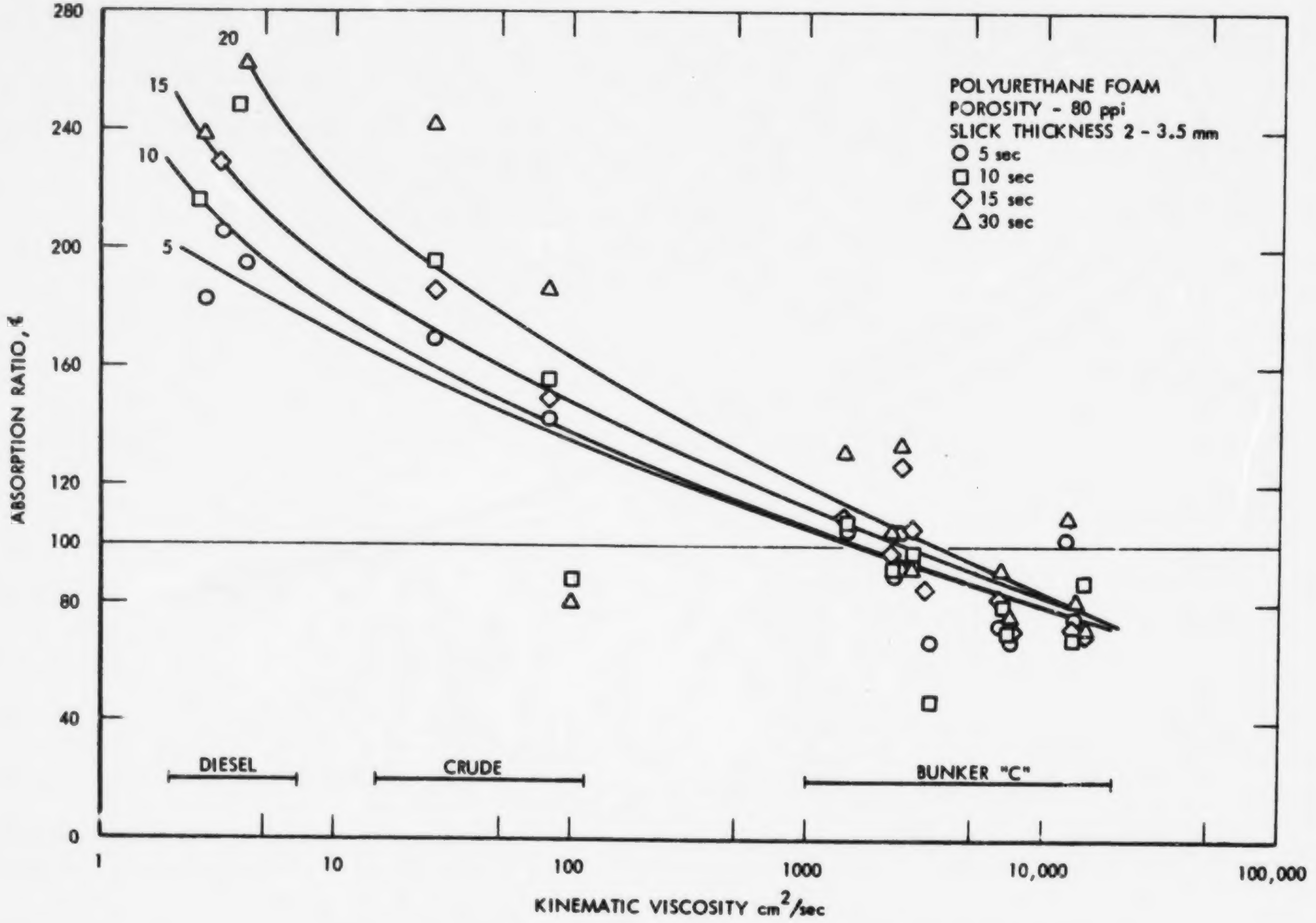


FIGURE 29 - EFFECT OF VISCOSITY AND RESIDENCE TIME ON OIL ABSORPTION

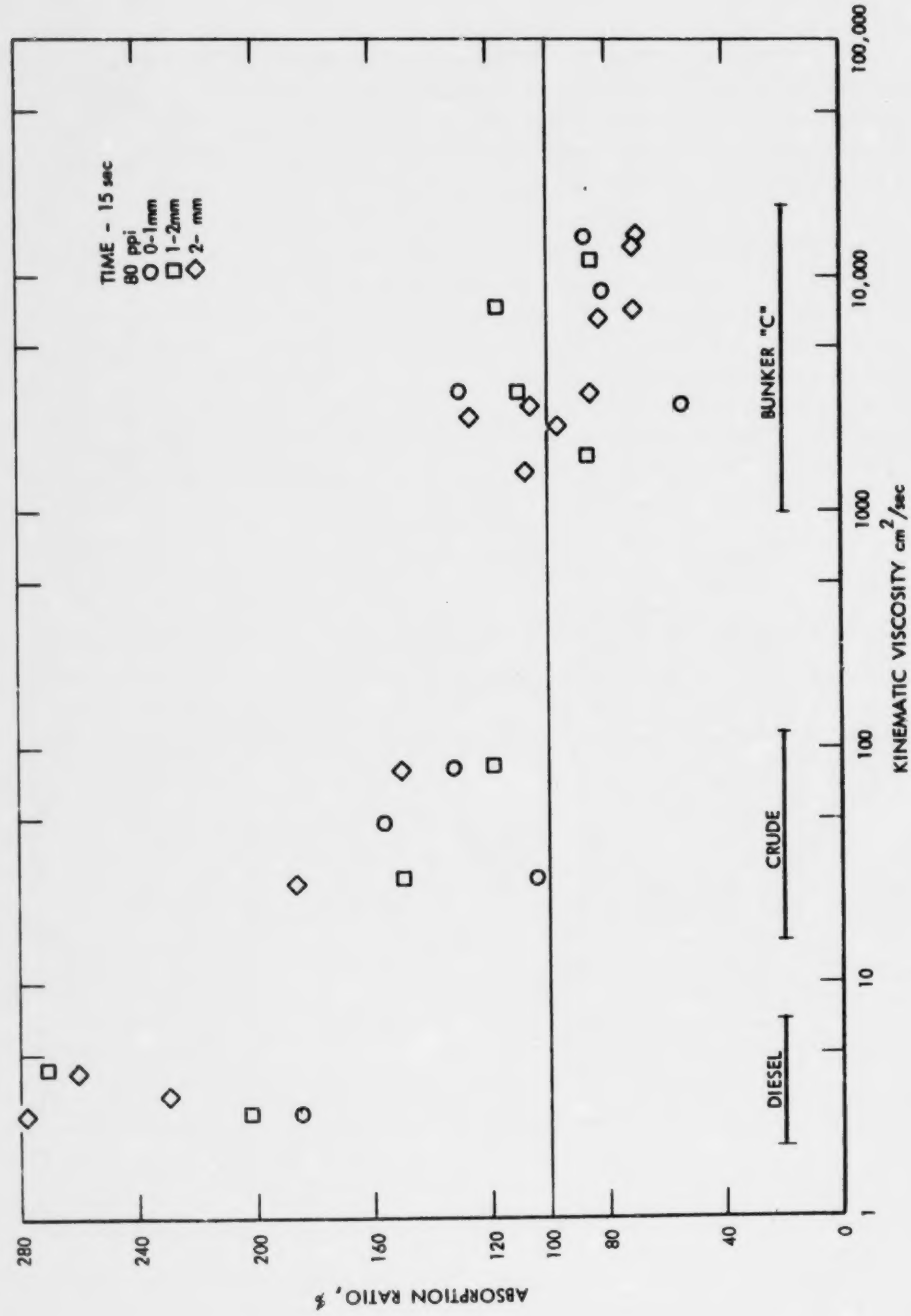


FIGURE 30 - EFFECT OF VISCOSITY ON OIL ABSORPTION

where absorption ratios dropped as the viscosity was reduced, rather than following the increasing trend shown on the other figures. It is also shown on Figure 24 where the points which represent some diesel oil experiments are very low, again because of rapid draining from the more open structure of the 30 ppi grade. This phenomenon had a much smaller effect on the results of the 80 ppi grade.

No drastic differences were noticed between absorption ratios from slicks of different thicknesses which actually means that absorption rates are affected by the oil slick thickness and are increased as the thickness is increased. The following table presents absorption influxes for an imaginary oil, having a kinematic viscosity of 100 cm^2/sec, and a specific gravity of .9 gr/cm^3. The fluxes were calculated for 30 seconds of absorption, where absorption values were picked from the curves of Figures 24 through 29.

TABLE 33

Oil Absorption Fluxes

Sorbent Type PPI	Slick Thickness mm	Absorption Influx* gr/sec cm^2	
30	1	5.35*	10^{-3}
30	2	10.35*	10^{-3}
30	3	10.80*	10^{-3}
80	1	4.50*	10^{-3}
80	2	9.10*	10^{-3}
80	3	14.78*	10^{-3}
		* Area of chip - 103.5 cm^2	

Except from the flux in the 3 mm 30 ppi case which is low in comparison because of higher drainage, the fluxes increase almost linearly with the slick thickness.

Based on the results of this task it has been concluded that 80 ppi polyurethane foam should be used as the sorbent material for low viscosity oils. Either grade may be used on high viscosity oils such as Bunker "C". The figures relating the absorption ratio to the parameters of oil viscosity, slick thickness, residence time and foam porosity may be used in engineering estimates of sorbent coverage required for complete removal or the oil recovered with 100 percent coverage.

APPENDIX B

DEVELOPMENT OF THE SORBENT BROADCASTING SYSTEM

The objectives of this task were:

(1) Develop and demonstrate a means of distributing sorbent material chips, on an oil slick, more or less evenly across the inner width of the craft at its forward end.

(2) Develop and demonstrate a pneumatic system for conveying chips from the oil removal section of the craft to the distribution device.

These objectives were accomplished with model tests. Due to the specialized nature of the problem, the model size and other parameters were near full scale to reduce scaling problems in the prototype design stage. The resulting design information is thus limited to craft employing the same basic concepts and of the same order of size and capacities as the model.

Before selecting basic parameters for the model, a small scale experiment was conducted to examine basic questions. At that time the intent was established to conduct most of the experiments with a material having greater density than the candidate material. This was done to simulate the weight effects of retained oil in regenerated chips while avoiding the problems associated with handling regenerated chips. Only those tests necessary to check for possible problems associated with oily material were conducted with regenerated chips. This approach was taken based on experience gained in previous work with the sorbent material. Indications were that the porous and fibrous surface of the material did not permit large areas to come into contact and it was felt that stickiness would not be a problem. Weight is of course a consideration in conveying and even the small amount of oil retained in a thoroughly squeezed chip is enough to increase its weight by a factor of two.

Closed cell polyurethane foam, available in a non-rigid form and with a density about twice that of the candidate material, was used for most of the testing.

STAGES IN THE DEVELOPMENT OF THE DISTRIBUTION DEVICE

Passive Nozzle Developed on Small Scale Experiment

The small scale experiment produced a passive distribution nozzle in the form of a transition from a circular duct to a wide, shallow, rectangular outlet. Thus in the horizontal plane, diffusion occurred, supplying width to the sorbent distribution pattern. The length of the nozzle was minimized and internal vanes were installed to reduce the effective diffusion angle.

There was concern that the leading edges of these vanes might trap sorbent chips if the chips were excessively "sheet-like"; that is thin for a given set of outline dimensions. This did in fact occur but it appeared that for 3-inch square chips (candidate size for full scale) a 3/8-inch thickness provided enough stiffness so that chips would not fold completely over the leading edges and be permanently trapped.

Further, it was felt that if the dimensions between leading edges were kept large relative to chip dimensions, it would not matter if some chips were trapped.

Passive Nozzle Tested on the Full-Scale Model

A similar nozzle for the full-scale model was designed and fabricated of sheet metal. Vanes were of cardboard, temporarily taped in place since some trial and error was expected in determining their location (Figure 31).

This nozzle performed quite well in early tests when material feed rates were still relatively low. Distribution patterns were sufficiently wide and fairly even (Figure 31). At rates above about 25 percent, however, the nozzle became plugged with chips at the vanes leading edges.

Passive External Plate Distribution Device

It was not certain whether the plugging was caused by higher chip concentration or the reduced speeds which are a consequence of increased chip rate. It was thought that the conditions which precipitated a plug might be temporary and that if they did not occur in a closed area, a plug might not fully develop. Based on this reasoning, a distribution

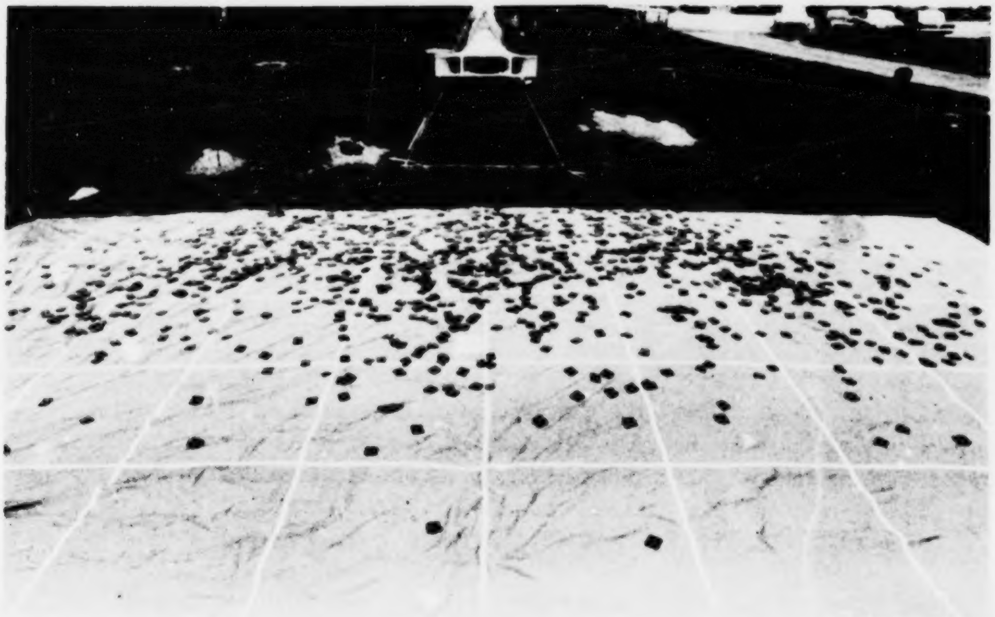


FIGURE 31 - CHIP BROADCAST PATTERN ACHIEVED IN EARLY TEST
(Grid Spacing = 4 feet)

device was constructed which was essentially an open nozzle. Splitter plates were located several inches away from the conveying duct outlet. The plates were less efficient than the nozzle at directing flow to the sides, but with leading edges located external to the duct, it was hoped a complete plug would be unable to develop.

Higher chip rates were obtained with this concept (about 50 percent) but eventually, plugs did occur unless the plates were moved so far away from the outlet that distribution became unsatisfactory. In fact, distribution patterns were never completely acceptable with the external device even at low chip rates.

Flexible Ducting Nozzle

Failure to achieve adequate chip rates with a passive nozzle forced a decision to accept the penalties associated with an active distribution device. It is conceivable that a thicker, stiffer chip would have been compatible with a passive nozzle but the extra material would be wasted in terms of oil recovery and impose acquisition and storage penalties.

The first approach to an active distribution device employed a section of flexible ducting attached to the conveyor outlet. The open end of the flexible section was free to swivel 45 degrees to each side about a vertical axis. This was a mechanically and structurally neat installation but it failed by plugging. The ducting was inexpensive, fabric covered, coiled wire construction, and it is felt the plugging began in the ridges on the compressed side of the duct in the fully deflected position.

Movable Parallel Plate Nozzle

In the meantime, while awaiting delivery of the flexible duct, another concept was developed and tested with more success. Two rectangular plates were hinged at the vertical edges of a rectangular outlet section. Their free ends were connected with a link. A horizontal plate was mounted above and below this movable plate unit. The result was a 2-foot-long, rectangular cross section portion of duct which could swivel 45 degrees to either side of center. The geometry is such that cross sectional area is a minimum at the sides and the increased outlet speed is beneficial in obtaining lateral throw.

This device was capable of passing chips at the highest rates achievable with the existing chip feeder box. A plug did develop in one test at high chip rates. It occurred in the sharp corner produced when the nozzle is fully deflected. The sharpness of the turn will be reduced on the prototype design.

EXPERIMENTAL EVALUATION OF SELECTED DISTRIBUTION DEVICE (MOVABLE PARALLEL PLATE NOZZLE)

Description of the Model and Experiment

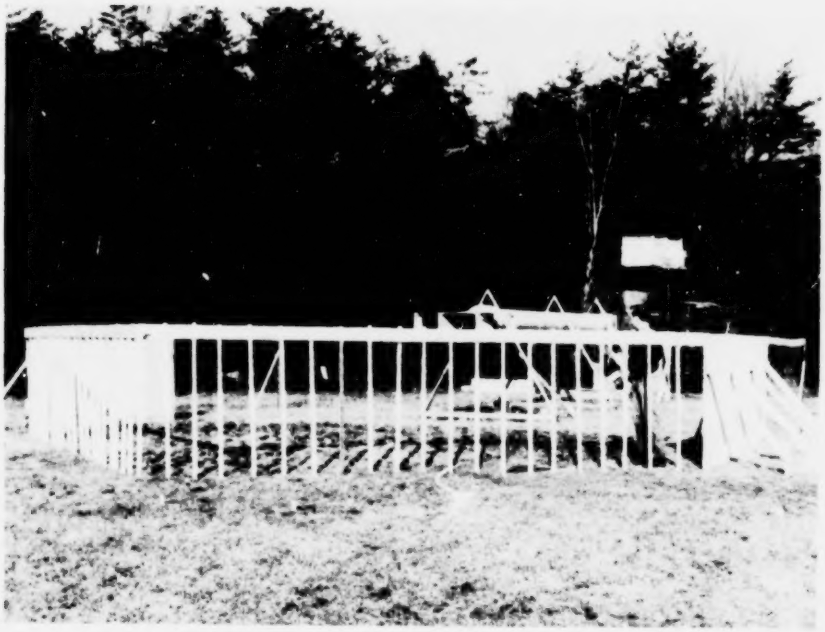
Figure 32 shows the nozzle installed on the full-size model of the broadcast system. The forward structure of a conceptual craft was also simulated. The flotation pontoon walls act as windbreaks as well as chip containment devices. The forward portion of the side screens serve a containment function and the simulated debris rake serves a certain containment role since its members must be large enough to provide significant strength on a prototype. The nozzle movement,which would be powered on a prototype, was performed by hand in the experiment.

Broadcast distributions were defined by determining the number of chips deposited in each of eight, 4-foot-wide strips running parallel to the model centerline. This method was satisfactory for winds less than about 8 mph. In higher winds, chips would not stay fixed on the grass surface of the test area and quantitative measurements could not be made. Data are available only in the form of photographs taken during and immediately after these tests.

Broadcast Patterns Calm and Light Winds

Quantitative broadcast pattern data are presented in a manner showing deviation from the optimum, which is an equal number of chips in each longitudinal strip. Some data from the external plate device are presented in Figure 33 to illustrate its ineffectiveness in producing uniform distribution. Results for the selected nozzle concept are shown in Figure 34.

Some of these tests were conducted in winds up to about 6 mph at 30 to 40 degrees off the bow and it appears that irregularities in nozzle motion and chip rate have more effect on distribution than winds of this strength.



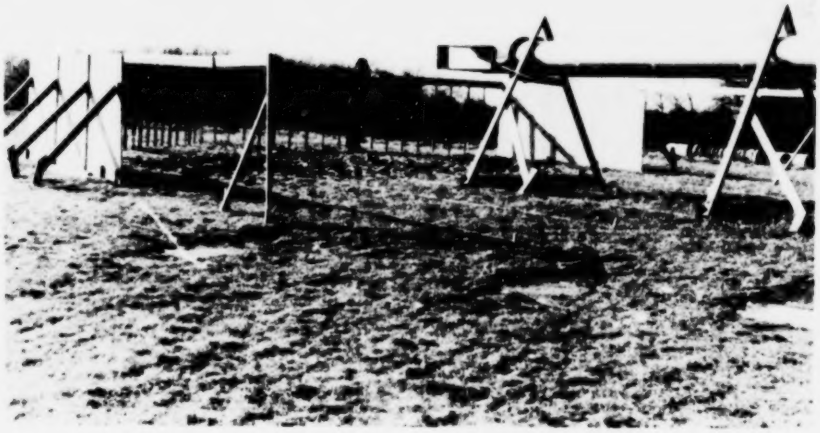
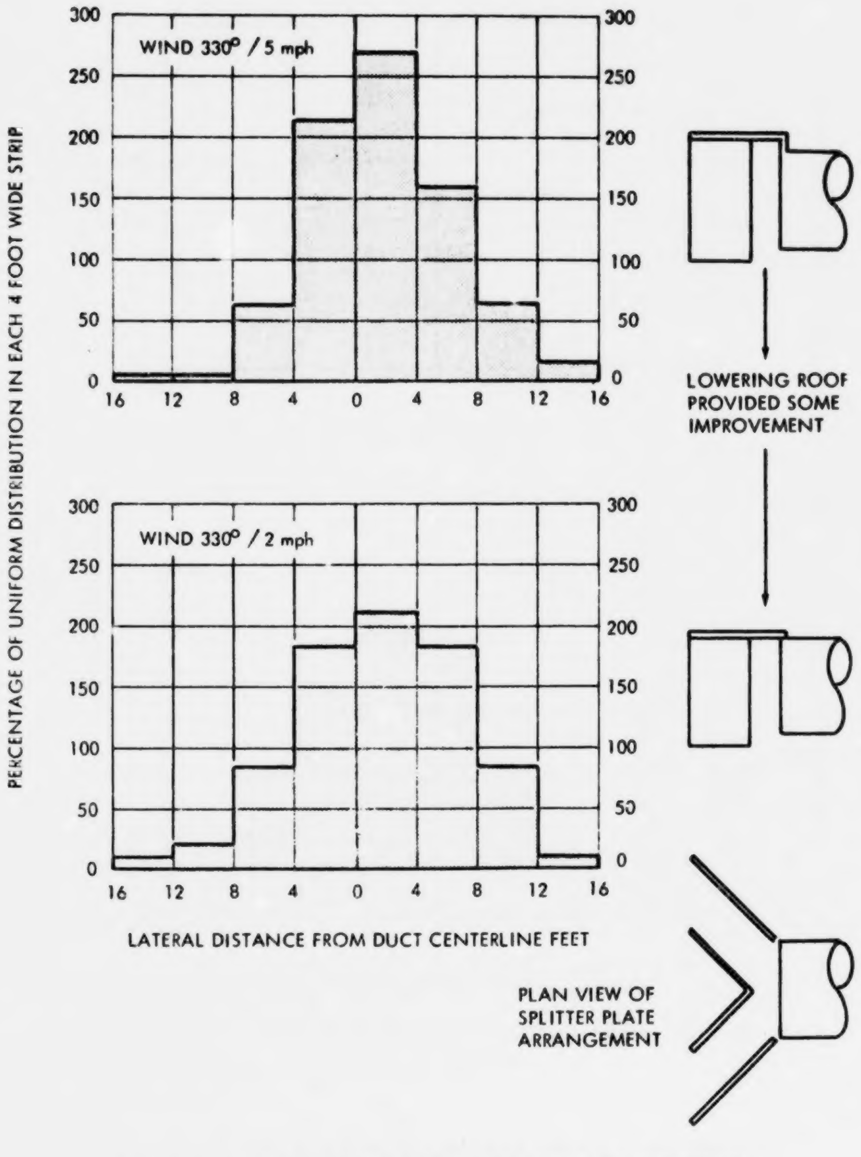


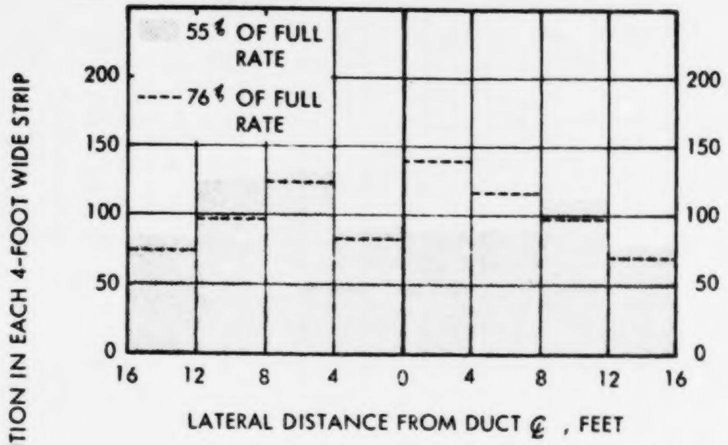
FIGURE 32 - SIMULATED DEBRIS RAKE, FLOTATION PODS, AND SIDE SCREENS ERECTED AT DISCHARGE END OF BROADCAST EXPERIMENT



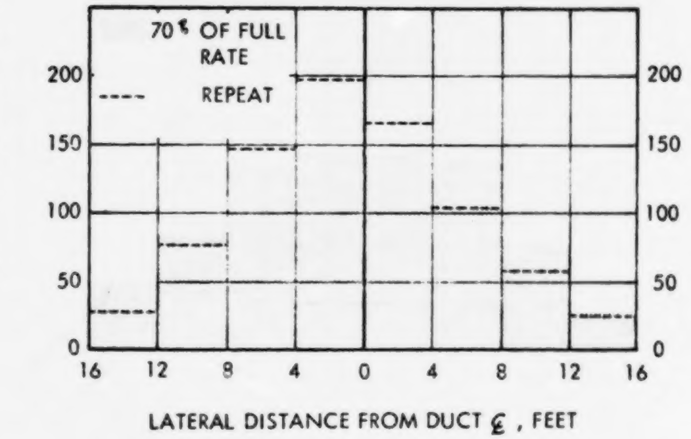
LOWERING ROOF PROVIDED SOME IMPROVEMENT

PLAN VIEW OF SPLITTER PLATE ARRANGEMENT

FIGURE 33- CHIP DISTRIBUTIONS OBTAINED WITH PASSIVE EXTERNAL PLATE DEVICE



(B) NOZZLE MOVEMENT: RAPID IN CENTER,
SLIGHT PAUSE AT EACH SIDE.



(A) NOZZLE MOVEMENT: STEADY;
NO ATTEMPT TO WEIGHT ANY AREA.

FIGURE 34 - CHIP DISTRIBUTIONS OBTAINED WITH MECHANICAL NOZZLE. (Wind from calm to 6 mph at 30 degrees off the bow)

The data show that if nozzle motion is slowed near the sides, distribution satisfactorily close to uniform can be achieved in cross winds up to about 6 mph. If the wind is nearly on the bow, distribution should remain satisfactory in considerably stronger conditions.

Strong Wind Patterns

Strong crosswinds had a pronounced effect on distribution patterns. An examination of photographs taken of tests conducted in 14 and 20 mph winds at 45 to 60 degrees off the bow indicate distributions similar to that shown in Figure 35. Winds from this direction probably have more effect than head or beam winds. Head winds, of course, produce no asymmetry, and crosswinds are more effectively blocked by the pontoon sidewalls.

The non-uniformity in broadcast patterns caused by winds is not an easy problem to attack since any structure added as a shield carries its own penalties. The best approach may be to provide for manual control of the nozzle motion and use this means to achieve best possible slick coverage in strong winds.

Sorbent Loss Rates

Some sorbent material will be lost in operation and the magnitude of the losses must not be unreasonable in terms of sorbent material make-up capacity. In all broadcast tests conducted in conjunction with the simulated bow, the number of sorbent chips deposited outside of the enclosure was determined (chips thrown through the debris rake were not considered lost unless deposited outside of the projected line of the pontoon wall). These losses are presented in Table 34 as a percentage of total chips broadcast in each test. Except for tests 47 and 52, a conservative average loss rate is about 2 percent.

Tests 47 and 52 are considered unrealistic compared to the prototype counterpart for a combination of reasons. Chip rates were low and because of the high speeds associated with low rates, chips were thrown a maximum distance. High speed alone does not produce loss but for these tests, the nozzle was mounted horizontally for convenience of assembly.

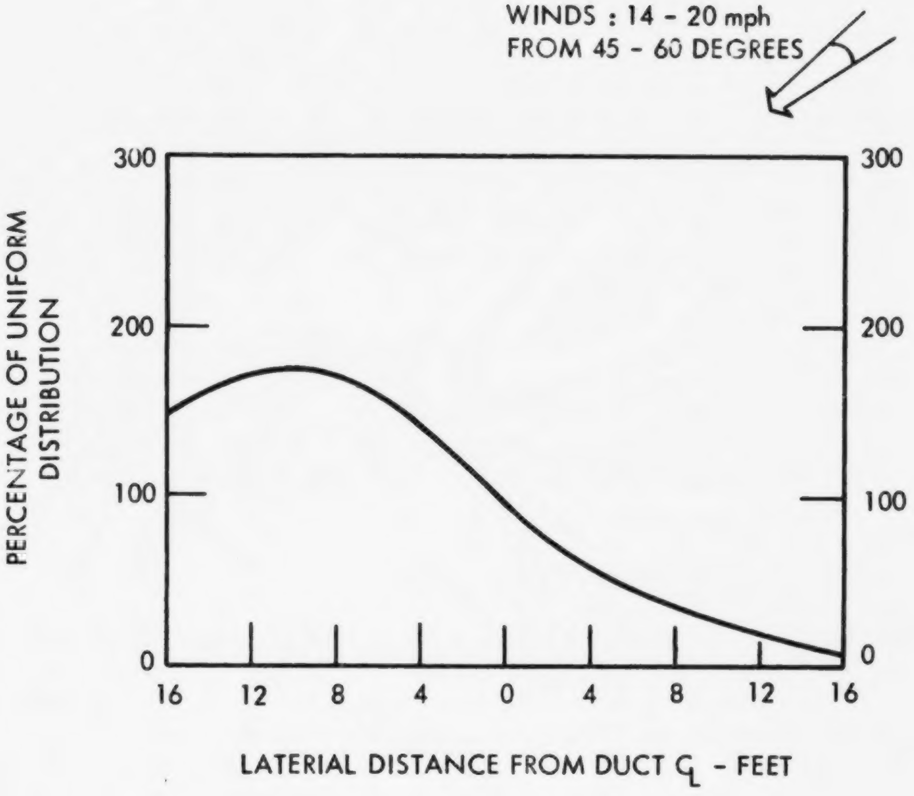


FIGURE 35 - TYPICAL EFFECT OF STRONG WINDS ON CHIP DISTRIBUTION PATTERNS

TABLE 34

Sorbent Chip Loss Rates Experienced in Full-Scale Model Tests

Test No.	Wind Conditions	Chips Lost percent	Comments
45	Calm	2	
46	Calm	0.15	Losses occurred over top of pontoon. Canted nozzle should reduce this somewhat.
47	Calm	4.7	73 percent of losses were fwd through rake. Test was at relatively low rate/high speed. Canting nozzle should reduce this type loss.
48	330°/6 mph	1.7	50 percent of losses were fwd through rake.
49	045°/14 mph	1.9	
50	045°/8 mph	1.6	
51	240°/5 mph	0.15	About same lost on both sides.
52	060/14 mph	5	Fairly low chip rate and high speed probably contributed to high losses
53	060/20 mph	1.6	Nozzle canted downward. All chips lost downwind side.

1. Rates are percentages of total chips broadcast in that tests.
2. Wind directions are relative to model centerline.

Later, the nozzle was canted downward about 10 degrees with the intention of reducing this type of loss. That this was fairly successful is shown by the 1.6 percent loss rate in test 53 conducted at nominally the same rate as test 52 with its 5 percent loss rate. It is therefore concluded that a loss rate of 2 percent of the number of chips being broadcast should be considered typical in strong cross winds. It is unlikely that it can be lower than 1 percent. In winds of 10 mph or in headwinds, the loss rate should drop to about 1 percent and probably 0.5 percent in winds of less than 5 mph

Based on 1170 - 3 x 3-inch chips per second required for nominal 100 percent area coverage to recover 10,000 gallons/hour from a 1.5 mm slick, these loss rates translate into makeup feeds of 84,200 chips/hour (165 cubic feet/hour) in strong crosswinds to 21,040 chips/hour (41 cubic feet/hour) in winds of less than 5 mph.

DEVELOPMENT OF THE SORBENT CONVEYING SYSTEM

Pneumatic conveying is the selected method of transporting sorbent material from the regenerating apparatus at the after end of the craft to the forward end where it is distributed on the slick and begins the sorption process. The conceptual design envisioned sorbent chips discharging from the regeneration device into the intake of an axial flow fan which exhausted into a circular duct, the duct then conveying the chips to the distribution device forward.

Development of Conveying System Concepts

The literature pertaining to pneumatic conveying which could be located offered little guidance with regard to low density material in a chip form and so as mentioned previously, a small experiment was devised. The primary purpose was to investigate air speeds required to properly convey the chips.

A 12-foot-long/9-inch diameter duct was constructed from clear plastic so that observations could be made. A one horsepower centrifugal blower with a materials handling wheel was obtained (a centrifugal blower for this size model was more readily available and less expensive than an axial flow fan).

It had been hoped to feed chips through the blower but it was found that the wheel progressively accumulated chips until either it became effectively plugged or unbalanced. The wheel was observed with a stroboscope and it was observed that some chips folded over the blade leading edges and that aerodynamic forces were great enough to keep them there. The blades incorporated swept leading edges so that a component of centrifugal force acted along the leading edge. Stringy material for which the wheel was designed, should slide out and around the open tips. The sorbent material, however, exhibited too large a friction coefficient for this to take place.

Two venturi injectors were constructed. The first had a circular cross section which was too inefficient in terms of feed area compared to cross sectional area. Thus a rectangular cross section injector was constructed.

A series of tests was conducted to determine the effects of air speed on conveying characteristics. Speed was varied by choking the blower inlet. Material properties were also varied in several directions. Two material densities and two chip sizes(3 by 3 inches and 1-1/2 x 1-1/2 inches) were used. The material was 1/4 to 3/8-inch thick. High-speed films were taken of a section of the clear duct.

Examination of the films indicated that a speed of about 30 feet per second was required if the small chips were to be evenly distributed vertically in the duct. The visual effect of speed was not distinct however, and conveying was not noticeably poor until a speed of about 25 feet per second.

Results for the larger (3 by 3 inches) chips were more difficult to interpret as were differences between the two material densities. The large chips were too large for the duct and collisions with the walls were too frequent to judge conveying quality.

It was judged that 30 feet per second for 1-1/2 by 1-1/2 in. chips with a density of 3.6 lb/cubic foot was the minimum speed for good conveying. A dimensionless parameter similar to the Froude number was used for scaling. This parameter is defined as

$$\frac{V}{\sqrt{\frac{\gamma_m}{\gamma_a} g\ell}}$$

where

V = duct speed-ft/sec,

γ_m = density of material - lb/ft^3,

γ_a = air density - lb/ft^3, and

ℓ = chip thickness, ft.

It was felt this relationship could be applied as long as chip size became no greater than about 1/6 of the duct diameter. This was the situation with the smaller chips in the small experiment when wall collisions did not seem to dominate the mechanism. On this basis, a minimum speed of about 42 feet per second was required for the full-size model using 3 by 3 inch chips.

An important effect revealed in the films was that large, thin chips are too limp for the process and upon contact with walls, tend to bend and collapse and sometimes flatten completely against the wall. The result is a very inefficient transport mechanism and it was decided to make full-scale chips stiff enough to reduce this type of loss. A thickness of 3/8 in. for 3 by 3 inches square chips was selected.

Design of Full-Size Model

Table 35 shows the type of losses which were accounted for in designing the model. Reference 1 indicated an axial flow fan is sufficient to handle material to air ratios (by weight) of about 2. Initial calculations called for a fan output of about 400 cfm at a static pressure of about 3 inches of water. This pressure is near the limit of a basic axial flow fan. Straightening vanes behind the fan can increase the capability, but it was felt the leading edges of the vanes would greatly reduce the chance that chips could be fed through the fan. The latter was important since a centrifugal blower wheel design was located which seemed to show promise as a

		TYPICAL CALCULATED VALUES $L=70$, $D=1.5$ $V=45, W_m$ 9 lb/sec
1. AIR FRICTION IN DUCT $h_{air} = \frac{V^2 / 2g}{69.4} \left[f \times L/D + 1.5 \right]$	$f = 0.013$ FROM PIPE FLOW DATA 1.5 = EXPERIMENTALLY DETERMINED NOZZLE LOSS (When deflected)	0.75 INCHES OF WATER
2. CHIP FRICTION IN DUCT $h_{Chips} = \frac{C \times W_m \times L}{W_a \times 69.4}$	C IS A "FRICTION COEFFICIENT" AND ≈ 2.5 FROM EXPERIMENTS	1.70 INCHES OF WATER
3. ACCELERATION OF CHIPS $h_{accel} = \frac{W_m \times V_m^2 / 2g}{W_a \times 69.4}$	IF ACCELERATION TAKES PLACE AT BLOWER OUTLET. OTHERWISE THIS SHOWS UP AS MOTOR POWER INCREASE.	0.67 INCHES OF WATER
4. POWER INCREASE IN BLOWER $HP = \frac{W_m \times V_{tip}^2}{2g \times 550}$	EXPERIMENTS SHOW NET EFFECTS OF CHIP + AIR FLOW IN BLOWER INCREASE THIS POWER	4 HP

TABLE 35 - TYPES OF SYSTEM LOSSES

chip handler and renewed the hope that a venturi would not be needed. The wheel design is shown in Figure 36. Essentially all the centrifugal force acting on a chip which has folded over a leading edge is directed along the edge, which hopefully would be sufficient to clear the blades.

A centrifugal flow blower with the wheel mentioned was specified for the model. It was powered with a 7-1/2 horsepower motor.

The material ratio of 2 and 45 feet per second speed yield a duct diameter of about 16 inches which was increased slightly to 18 inches. Sheet metal ducting was obtained and a 7-foot-long clear plastic section was constructed for observation purposes. Total duct length was about 58 feet and the nozzle was expected to throw 10 feet to complete the 67-1/2 foot length established in the conceptual design. The duct was supported 5 feet above ground level to model prototype wave clearance.

Because of pessimism regarding feeding through the blower, an injector was also constructed. Initial tests with the blower indicated that chips were captured by the wheel and so the model was erected with the injector installed.

A sheet metal nozzle similar to that developed on the small model was obtained and trial vanes taped in place.

Sorbent chips were fed into the system with a batch conveyor apparatus. A 10-foot-long by 2-foot-square open box was constructed and the bottom and both sides lined with canvas strips attached at one end to the sides and bottom edges of a 2-foot plywood square. At the open end of the box, the bottom canvas was routed under the box and the side canvases around the sides of the box. When the free ends were simultaneously pulled toward the closed end of the box, a three-sided conveyor action took place, carrying up to 20 cubic feet of chips gradually over the lip of the box into the system inlet (Figure 3).

Chips were broadcast onto a 20 by 40-foot plastic tarpaulin marked with a grid.

The full-size experiment as originally designed and erected is shown in Figure 3.

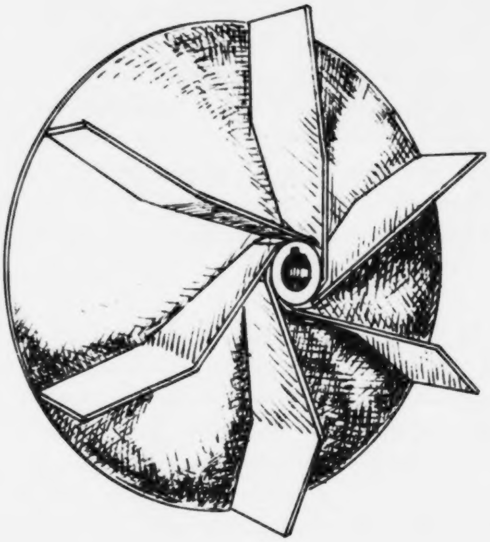


FIGURE 36 - THE BLOWER WHEEL DESIGN CAPABLE OF HANDLING SORBENT CHIPS

Tests and Problem Solving on the Model

It soon developed that the system could achieve only 10 percent of the required chip rate, limited by the injector. Various improvements increased this limit to about 33 percent. At this point it seemed that an injector was too inefficient in extracting power from the blower and further tests were made of the ability of the blower to pass chips. There was no progressive buildup of chips in or on the wheel and the model was rearranged to feed into the blower through the 90-degree inlet elbow and bell mouth which had been designed and built with the rest of the model components. Wheel RPM was also increased 12 percent to make more power available. With these two changes, feed rate increased to 66 percent before a new barrier was reached, choking in the blower inlet.

The 90-degree turn within a short distance of the blower has been identified as a potential trouble spot in the design phase. Rather than investigate methods of reducing the problem, it was decided to eliminate the turn by installing the blower on its side.

In this configuration, feed rates up to 95 percent were achieved and although speed dropped below good conveying, there was no indication of reaching a feed-rate limit. It is felt that 100 percent rate could have been achieved if the feed box had been larger.

Having demonstrated that sorbent chips could be conveyed the required 67-1/2 feet but faced with higher losses than had been anticipated, it was decided to shorten the duct to obtain higher air speeds at similar chip rates. The modified duct was 27 feet long from blower to nozzle outlet with the center of a broadcast pattern being about 10 feet further forward.

Tests Conducted with Regenerated Chips

As discussed earlier, the foregoing tests were conducted with heavier, dry chips. To verify the assumption of no differences between dry and regenerated chips, approximately 4 gallons of number 6 fuel oil were dumped into the blower inlet. The inside of the blower and the nozzle were thoroughly coated and the ducting was coated to a somewhat lesser extent. The nozzle was locked to one side to produce the worst condition.

Regenerated chips from Task 3 were conveyed and broadcast several times at high rate. No chips were retained in the blower or ducting and only two or three remained in the corner of the nozzle (this occasionally occurred with dry chips for that matter).

Engineering Requirements for the Conveyor

Enough chips were obtained to provide a 6-second test at 100 percent rate. This was a compromise between time enough to make measurements and the problems of working with a very large number of chips. Unfortunately, the chips exhibited a clumping property and entered the intake at a slightly non-uniform rate so that the system operated at a slightly unsteady condition. Data were not very accurate for these reasons.

Static pressure measurements were made in the blower inlet and just downstream of the blower outlet. Inlet pressure measurements were not of much value since it was not practical to provide a long enough straight section of duct to produce straight streamlines. All static pressure measurements had to be made with flush taps since a probe is not usable in the presence of chips.

Motor current was measured to supply data relating to power requirements.

Measurement of speed in the duct is a problem due to the chips. The inside of the duct could have been necked down to create a venturi but diameters and lengths required to produce adequate pressure differences looked to be impractical. The method used relied on a two-bladed paddle-wheel mounted in a slot in the duct wall. Paddlewheel RPM was measured with a servotach DC generator and calibrated with a pitot-static tube in the absence of chips. The flow is not homogeneous and chips move slightly slower than the air but it was assumed adequate to take the speed determined from paddlewheel RPM as both air and chip speeds.

Required Air Speed in Duct

Observations at the duct outlet and in the clear duct section installed during part of the model testing indicated that if speeds dropped below 40 feet per second, the chips no longer appeared as a uniform mass and gave the impression of moving in the lower part of the duct. This is in general agreement with the results of the small-scale experiment.

It is concluded that minimum air speed should be 45 feet per second to obtain good conveying.

Head Losses in the Duct

The head loss in the duct and nozzle is caused by air friction and chip friction. For engineering purposes, it was decided to account for air friction loss on the basis of standard pipe flow data as if there were no chips. Measured head losses were reduced by a pipe flow air friction loss and the remainder attributed to chip friction.

In accordance with Reference 2, chip losses were thought of as being the energy involved in a frictional force acting over the length of the duct in a time interval determined by chip speed. The frictional force is the product of a friction coefficient and a normal force equal to the weight of chips in the duct at any instant.

The friction coefficient was expected to be about 0.4 but the test data produced a value of about 2.3 (Figure 37). In hindsight, the tumbling and the unsteady speed of individual chips observed in the high speed films of the small model may be indicative of greater losses from air drag on individual chips than if the sorbent were in particle form. Also, some chips no doubt come to a stop against the duct wall and must be re-accelerated. Both types of losses appear in the experimentally determined "friction coefficient" in addition to material sliding along the duct.

Characterization of the system is simplified by the fact that nozzle effects seem to average out with nozzle movement as shown by the data points on Figure 37.

$$h_{chips} = \frac{C \times W_m \times L}{W_a \times 69.4}$$

h = HEAD LOSS IN INCHES OF WATER
C = FRICTION COEFFICIENT
L = DUCT LENGTH IN FEET
W_m = LBS OF MATERIAL / SECOND
W_a = LBS OF AIR / SECOND

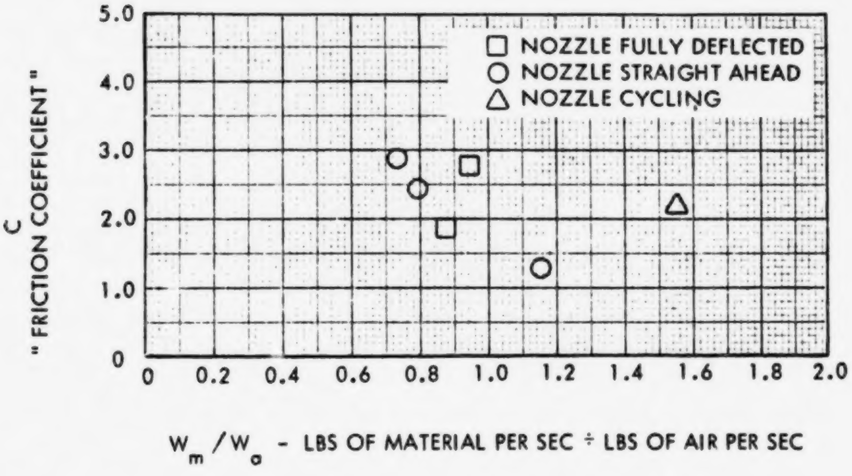


FIGURE 37 - EXPERIMENTAL "FRICTION COEFFICIENT" FOR HEAD LOSS DUE TO CHIPS FLOWING IN DUCT

Engineering Requirements for the Blower

The blower should be centrifugal rather than axial flow since in the head range required, an axial flow fan would require swirl recovery vanes which would prohibit feeding sorbent chips through the fan. It is important that feeding be done through the fan or blower since the alternative, an injector, is inefficient.

The blower wheel must incorporate certain features if it is to successfully handle the sorbent chips. The blades must extend radially into the hub to eliminate the axially aligned leading edge present on air handling wheels and some materials handling wheels. There must be no rim or front plate on the wheel so that chips are free to slide along the radial leading edges and clear the wheel.

Chip Effect on Blower Head

The presence of sorbent chips in the blower has the effect of reducing static head produced at constant RPM and discharge. The magnitude of this reduction is shown in Figure 38, where F_H is the ratio of effective static head delivered with chips to static head capability of the blower alone at a given RPM and discharge.

The effect of F_H on the prototype design will probably be a reduction in the material ratio to about 1 rather than 2 as originally intended.

Chip Effect on Blower Power

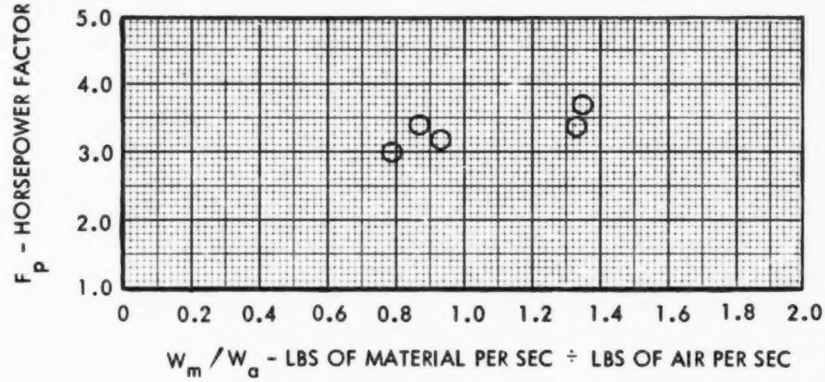
Enough power must be transferred to the chips to give them wheel tip speed. Some chips will no doubt slide along blade surfaces which should show up as a power increase.

Also, even though chips reduce head at constant capacity, it seems that efficiency is reduced even more so that power increases considerably more than might be allowed for.

Measured motor currents were converted to horsepowers. A horsepower due to air only was obtained from manufacturer's data at the test RPM and capacity. The difference between measured and air horsepower was attributed to the total effect

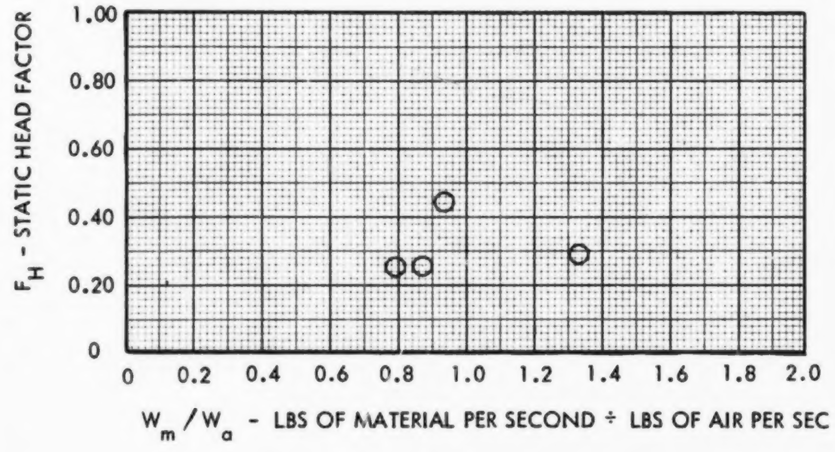
F_p = (POWER REQURIED - AIR ONLY POWER) ÷ (CALCULATED CHIP POWER)

CALCULATED CHIP POWER = $W_m \times V_{tip}^2 / 2g \times 550$



EFFECT OF CHIPS ON BLOWER POWER REQUIREMENTS

F_H = (EFFECTIVE STATIC HEAD PRODUCED) ÷ (STATIC HEAD EXPECTED WITHOUT CHIPS)



EFFECT OF CHIPS ON BLOWER STATIC HEAD

FIGURE 38 - EXPERIMENTALLY DETERMINED FACTORS WHICH ACCOUNT FOR THE EFFECT OF CHIPS ON BLOWER HEAD AND POWER

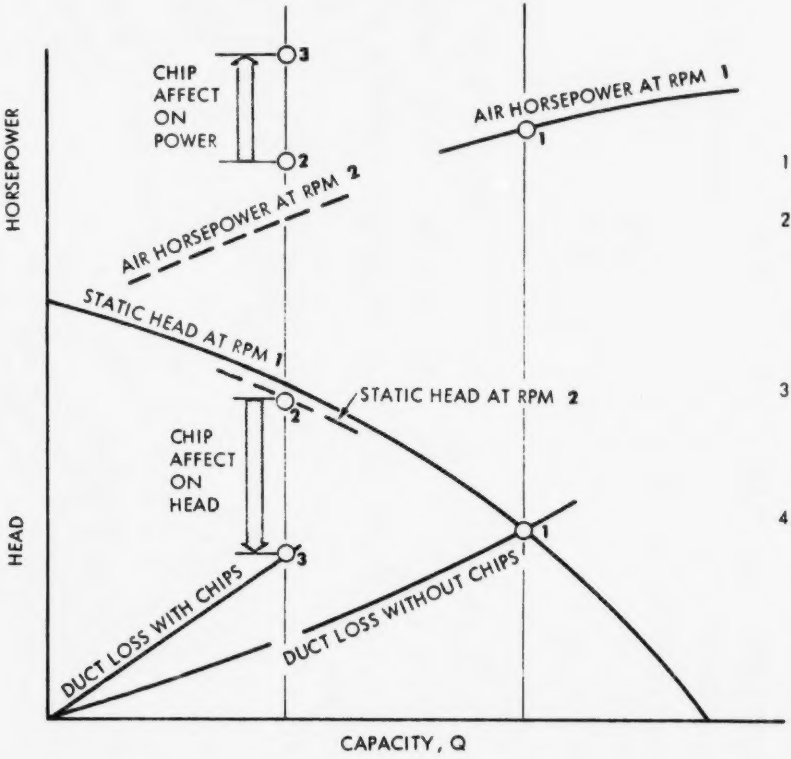
of chips. These powers were compared to the power required to accelerate the chips to tip speed to produce a measure of power efficiency to be applied in conjunction with the pressure efficiency discussed earlier. Values of this factor, F_p, are shown in Figure 38. This approach to power requirements implicitly includes the chip acceleration loss defined in Table 35.

Model of System Operation

Figure 39 presents a graphical model of a concept of the system which accounts for losses and the effects of chips on blower head and power.

Validity of Head and Power Factors

The sorbent broadcast model is a very specialized application of pneumatic conveying and the correlations produced by the tests cannot be expected to hold if applied to a system much different from the model. It was for this reason, of course, that the model was made as near the conceptual design as possible.



1. SYSTEM OPERATES AT POINT 1 WITH NO CHIPS BEING CONVEYED
2. IF CHIPS DID NOT AFFECT FLOW IN BLOWER, THEN WHEN CHIPS ARE CONVEYED, THE CAPACITY DROPS DUE TO DUCT LOSSES, POWER INCREASES OVER AIR HORSEPOWER TO IMPART TIP SPEED TO CHIPS, AND RPM DROPS VERY SLIGHTLY. SYSTEM WOULD OPERATE AT THE HYPOTHETICAL POINT 2
3. SINCE CHIPS DO AFFECT THE BLOWER, HEAD DELIVERED DROPS AND POWER INCREASES AND THE SYSTEM ACTUALLY OPERATES AT POINT 3 . POINT 3 MUST FALL ON A LINE WHICH DESCRIBES DUCT LOSSES.
4. IN DESIGN, POINT 3 IS THE KNOWN STARTING POINT.

FIGURE 39 - MODEL OF HEAD AND POWER INTERACTIONS BETWEEN BLOWER, DUCT, AND CHIPS

Sample Calculation

I. Design Conditions

1.	Nominal slick coverage	4400 ft^2/min (conceptual design)
2.	Density of regenerated chips	3.6 lb/ft^3
3.	Chip dimensions	3 x 3 x 3/8 in.
4.	From 1,2, and 3, chip rate	1172 chips/sec
5.	From 2 and 3 chip weight	0.00705 lb/chip
6.	Duct speed with chips	45 ft/sec
7.	Duct length	67.5 ft (conceptual design)
8.	Weight sorbent/weight air	1.0 nominal
9.	Density of air	0.075 lb/ft^3

II. Duct size calculation

1. Weight of material, $W_m = 1172 \times 0.00705 = 8.26$ lb/sec
2. Weight of air, $W_a = 1.0 \times 8.26 = 8.26$ lb/sec
3. Total volume flow rate Q = volume of sorbent + volume of air

$$Q = \left(\frac{8.26}{3.6} + \frac{8.26}{0.075}\right) \times 60 = 6746 \text{ ft}^3\text{/min}$$

4. Duct sectional area

$$Q = \text{Area} \times \text{Speed}$$

$$\text{Area} = 6746/45 \times 60 = 2.50 \text{ ft}^2$$

$$\text{Diameter} = \sqrt{\frac{4 \times \text{Area}}{\pi}} = \sqrt{\frac{4 \times 2.50}{\pi}} = 1.78 \text{ ft}$$

(21.36 in.)

III. Duct losses (Table 35)

1. Air friction, $h_f = \frac{V^2/2g}{69.4} \; f \times \frac{L}{D} + 1.5$

$$h_f = \frac{(45)^2}{69.4 \times 64.4} \; 0.013 \times \frac{67.5}{1.78} + 1.5 = 0.90 \text{ in. of water}$$

2. Chip friction $h_{chips} = C \times \frac{W_m \times L}{W_a \times 69.4}$

$$h_{chips} = 2.3 \times \frac{8.26}{8.26} \times \frac{67.5}{69.4} = 2.23 \text{ in. of water}$$

3. Total duct loss = air + chips

$h = 0.90 + 2.23 = 3.13$ in. of water

IV. System operating point (point 3 on Figure 39)

$Q = 6746$ ft^3/min

$h = 3.14$ in. of water

V. Inclusion of chip effect on head

From Figure 38, when $W_m/W_a = 1.0$

$F_h \approx 0.30$

∴ to deliver $h = 3.14$, blower must operate at an apparent condition,

$Q = 6746$

$H = 3.14/0.30 = 10.47$

(this is point 2 on Figure 39).

VI. Blower RPM and air horsepower at point 2. (Based on American Standard Size 21 long shaving type blower with a 36-1/2 inch wheel diameter)

1204 RPM

$17.41\ h_{p_{air}}$

VII. Ideal chip horsepower and allowance for chip effect on chip horsepower.

1. Wheel tip speed $= \frac{36.5 \times \pi \times 1204}{12 \times 60} = 192$ ft/sec.

2. Ideal chip power $= \frac{V^2_{tip}/2g \times W_m}{550}$ (Figure 38)

$$hp_{ideal} = \frac{(192)^2 \times 8.26}{64.4 \times 550} = 8.60$$

3. From Figure 38 when $W_m/W_a = 1.0$

$$F_p \approx 3.3$$

Actual chip power = Ideal chip power x F_p

$$hp_{actual} = 8.60 \times 3.3 = 28.38$$

4. Actual operating power = actual chip power + air power

$$H_p = 17.41 + 28.38 = 45.99$$

APPENDIX C

DEVELOPMENT OF THE HARVESTING CONVEYOR AND OVERALL OIL RECOVERY PERFORMANCE

The objectives of this task were:

1. Determine the conveyor inclination angle and speed for optimum performance.
2. Using the optimum conveyor operating condition, develop data on system performance as a function of the other operating parameters.

The system performance was defined in terms of the percentage of oil recovered from the slick and the percentage of oil in the recovered fluid. The performance goals given by the EPA were 100 percent recovery of the oil from the slick and in excess of 90 percent oil in the recovered fluid. The operating parameters which were studied in addition to the conveyor angle and speed included:

- Slick thickness and viscosity (oil type and temperature)
- Sorbent coverage
- Residence time
- Calm water versus waves

The harvesting conveyor test setup was installed in a 80-ft towing tank along with the sorbent chip distribution carriage. Figure 5 shows a picture of the harvesting conveyor which can be run at speeds up to 3.5 ft/sec with the variable speed drive installed. The conveyor consists of 1 in. mesh opening flat wire belt. Figure 6 shows a picture of the sorbent chip distribution carriage. This carriage is equipped with a moving belt feed device which feeds the chips to a rotating paddle wheel spreader. This device is used to distribute the chips in the tank in a random fashion.

The test procedure is to cover a 55-ft length of the tank with a known quantity of oil. The sorbent chip distribution carriage is then run down the tank at a fixed speed to distribute a known amount of sorbent on the slick. After waiting the required residence time, the harvesting conveyor follows down the tank and picks up the chips and drops them in a collection box. After the run, the chips in the box are regenerated and the amount of oil and water recovered is measured. The oil remaining in the tank is collected and measured to determine the amount of oil not recovered. Figure 7 shows a typical test in progress.

The initial tests were directed at determining the optimum conveyor angle and conveyor speed relative to forward speed. Typical results are shown in Figure 40. In this figure, the total percent of oil recovered and the percent of oil in the recovered fluid are plotted as a function of the conveyor speed ratio. The conveyor speed ratio is defined as

$$\frac{(\text{Conveyor Speed}) \times (\text{Cosine Conveyor Angle})}{\text{Forward Speed}}$$

The test conditions are noted in the figure. The total percent of oil recovered does not seem to be a function of the conveyor angle. However, it is a function of the conveyor speed ratio. At low speed ratios, the chip distribution density increases in front of the conveyor during collection. This slightly increases total percentage recovery of oil. This condition also forces more water into the chips so that the percentage of oil in the recovered fluid drops. At high conveyor speed ratios the percentage of oil in the recovered fluid also drops because of the entrained water droplets carried by the conveyor. The 45-degree conveyor angle is superior to the 30 degree angle since less water is recovered with the oil. The 45-degree angle results in less water because less water is entrained with the conveyor and there is a greater tendency for water to run off the chips. Tests in waves indicate they cause an increase in the percent of oil recovered. This is because the waves agitate the sorbent chips causing contact with a greater area of the slick. Observations indicate that the conveyor angle cannot be increased much above 45 degrees without the use of flights. Thus, based on these tests a conveyor angle of 45 degrees and a conveyor speed ratio of 0.7 seem to be optimum.

The system performance as a function of slick thickness and oil viscosity is presented in Figures 41 through 44. Figures 41 and 43 give the percent oil recovered and Figures 42

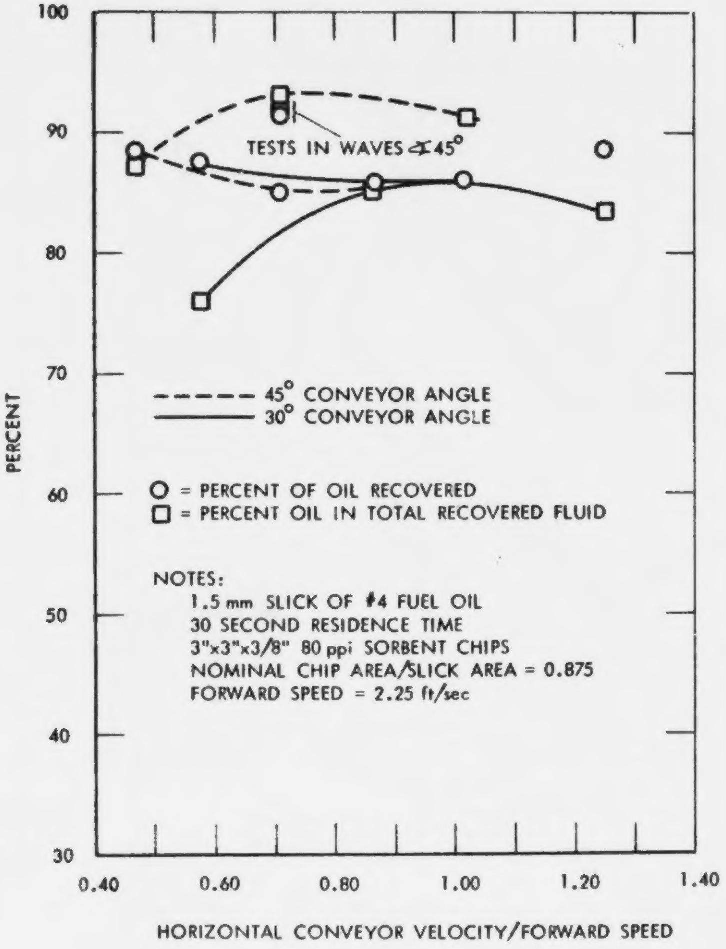


FIGURE 40 - HARVESTING CONVEYOR PERFORMANCE

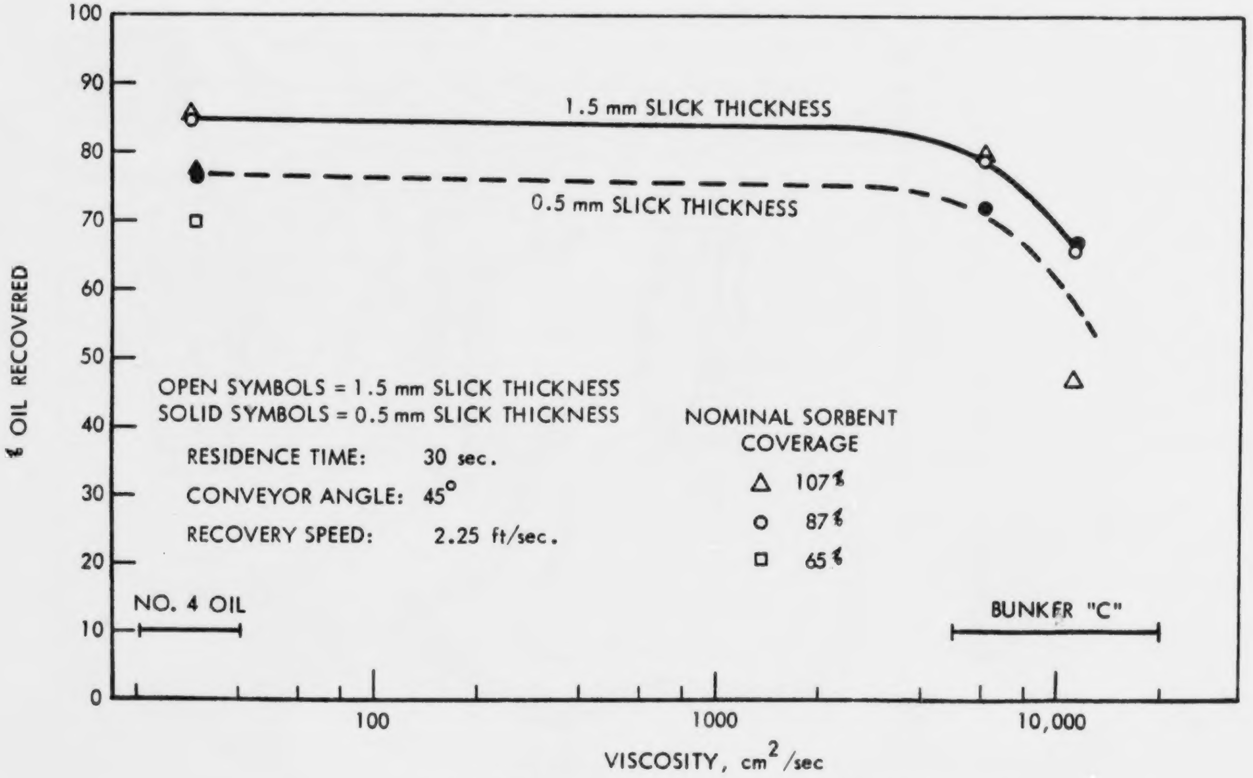


FIGURE 41 - OIL RECOVERY VS. VISCOSITY (CALM WATER).

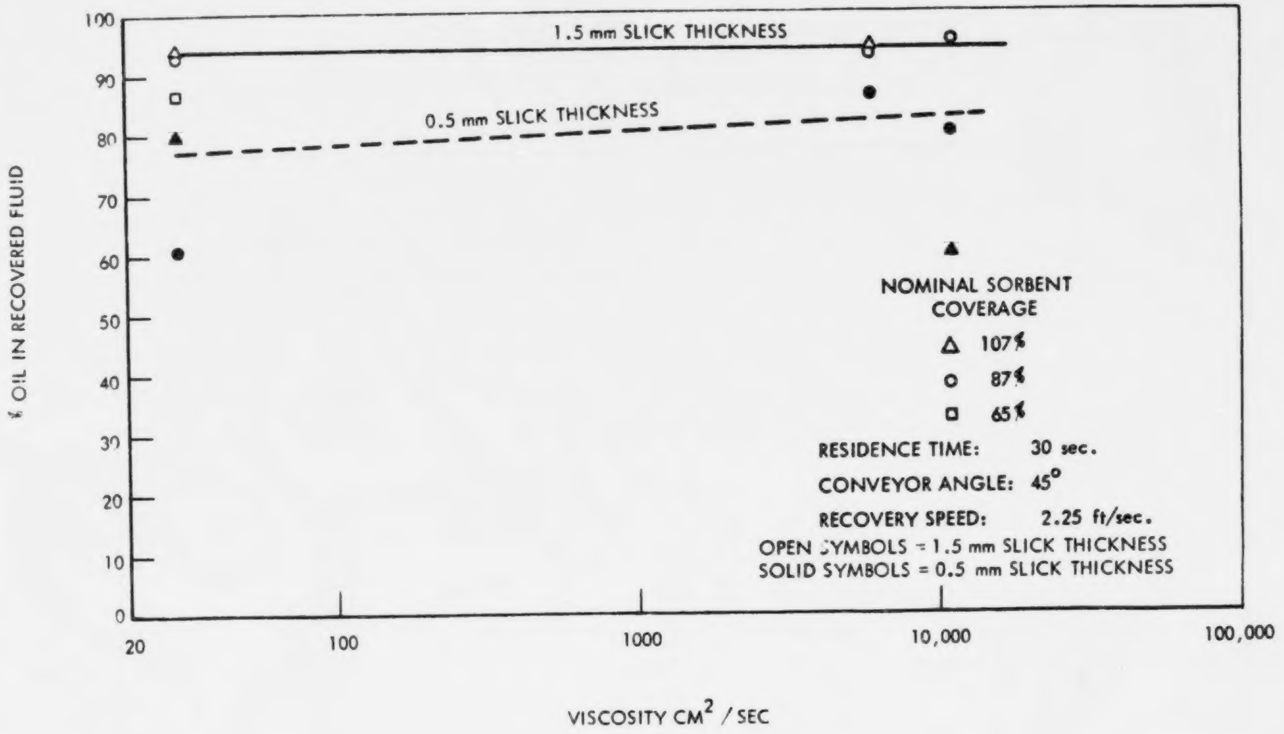


FIGURE 42 - PERCENT OIL IN RECOVERED FLUID VS. VISCOSITY (CALM WATER)

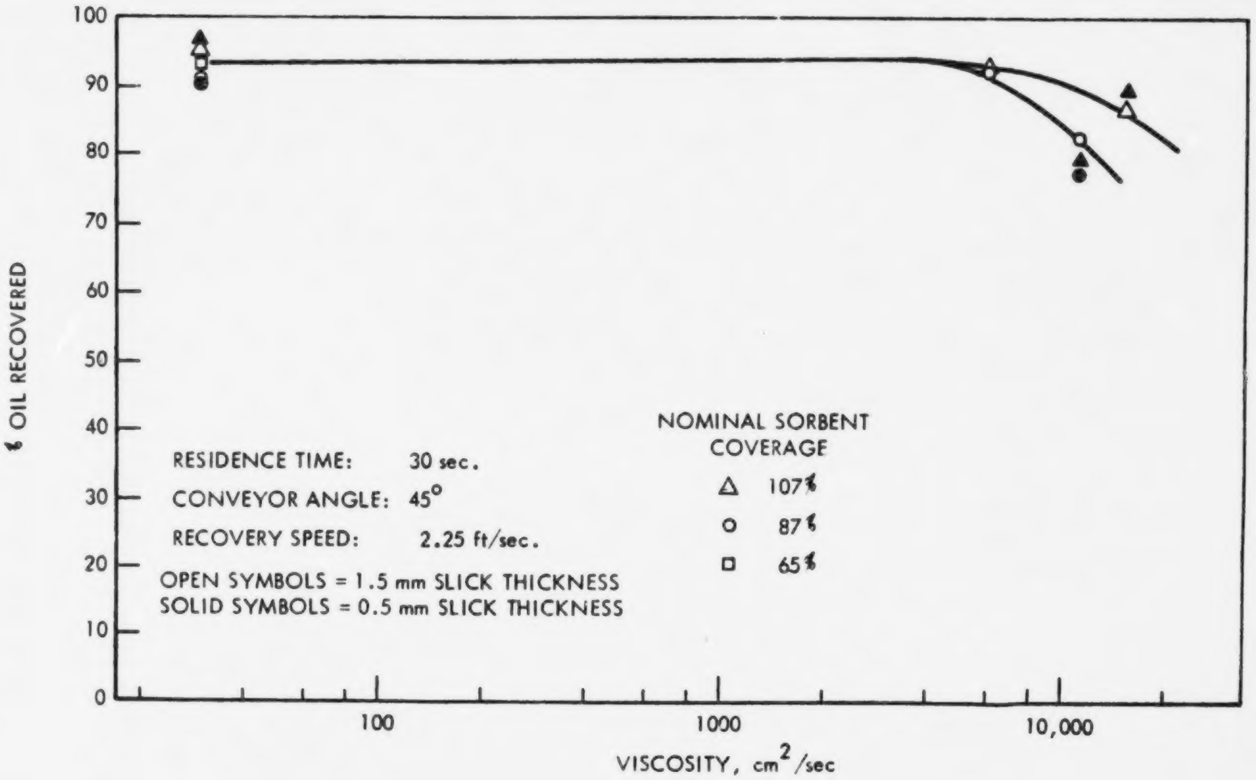


FIGURE 43 - OIL RECOVERY VS. VISCOSITY (WAVES)

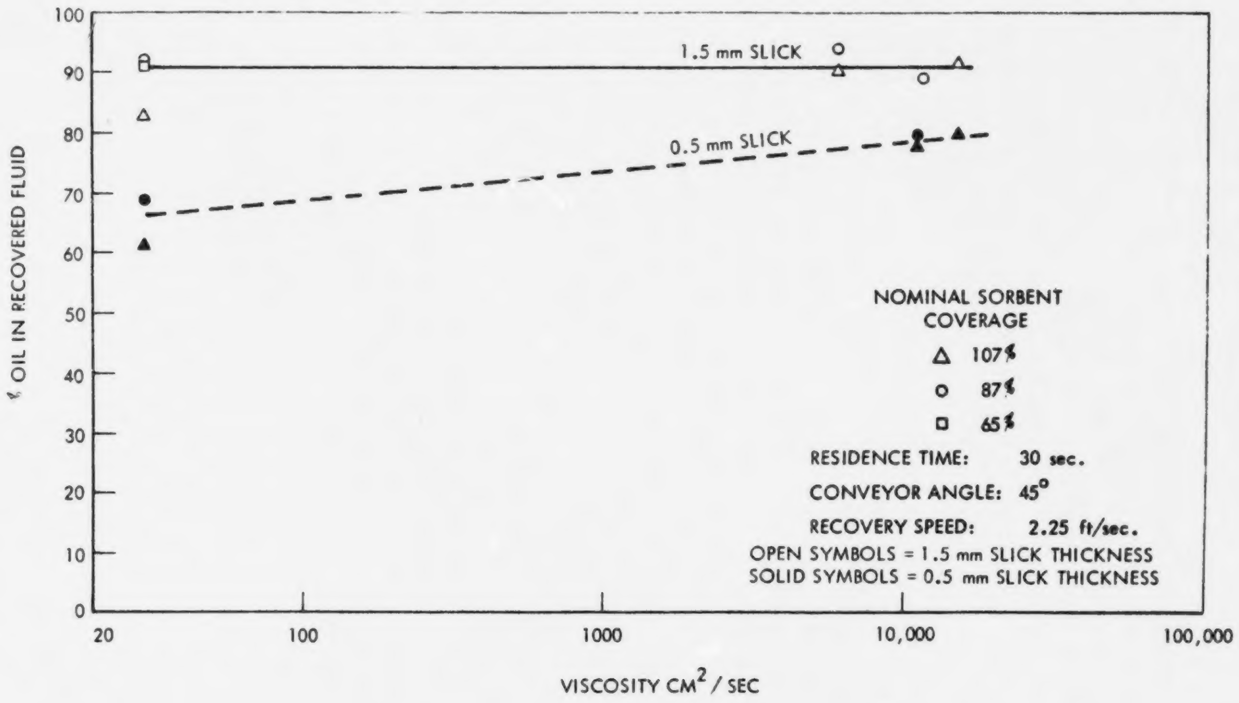


FIGURE 44 - PERCENT OIL IN RECOVERED FLUID VS. VISCOSITY (WAVES)

and 44 give the percent oil in the recovered fluid. Figures 41 and 42 are for calm water and Figures 43 and 44 are for waves of 3 inch height and 4 foot length. These figures are based on a sorbent residence time of 30 seconds. It should be noted that the tests were carried out with a two-dimensional section of the actual conveyor at prototype speeds, oil type and slick thicknesses with the prototype sorbent. Consequently, the results are applicable to the actual unit and scaling of the data is not required. The performance in terms of the percent of oil recovered and the percent oil in the recovered fluid is better in a slick of 1.5 mm thickness than in a slick of 0.5 mm thickness. This is as expected since the thicker slick provides more flow area into the sides of the chips and the larger volume of oil recovered tends to improve the percent oil in the recovered fluid. The percent recovery is better in waves because the waves agitate the chips causing them to contact a higher percentage of the surface. Figure 43 presents data which indicates that with small waves and a uniform sorbent distribution, the actual unit will recover over 90 percent of the oil in 0.5 mm and 1.5 mm slicks for oil viscosities up to 10,000 cm^2/sec. The 8 to 10 percent of the oil which is not recovered is due to the portions of the slick not contacted with sorbent, losses from chips on the harvesting conveyor and oil washed off the harvesting conveyor. Tests indicate that about 15 percent of the oil not recovered is washed off the harvesting conveyor and less than 5 percent is lost from the chips on the harvesting conveyor. Operation in waves also increases the amount of water recovered due to the agitation of the sorbent chips. Figure 44 indicates that in small waves the requirement for 90 percent oil in the recovered fluid can be satisfied in a 1.5 mm slick but not in a 0.5 mm slick. A further analysis of the water recovery rate is presented in a following paragraph.

The system performance in terms of percent oil recovery as a function of sorbent residence time is presented in Figure 45 for calm water and Figure 46 for waves. The important conclusion from these two figures is that there is little or no increase in the percent recovery for residence time in excess of 30 seconds for the slick thicknesses and oils tested. The percent of oil recovered does not tend to decrease rapidly until the residence time is reduced to 10 seconds or less.

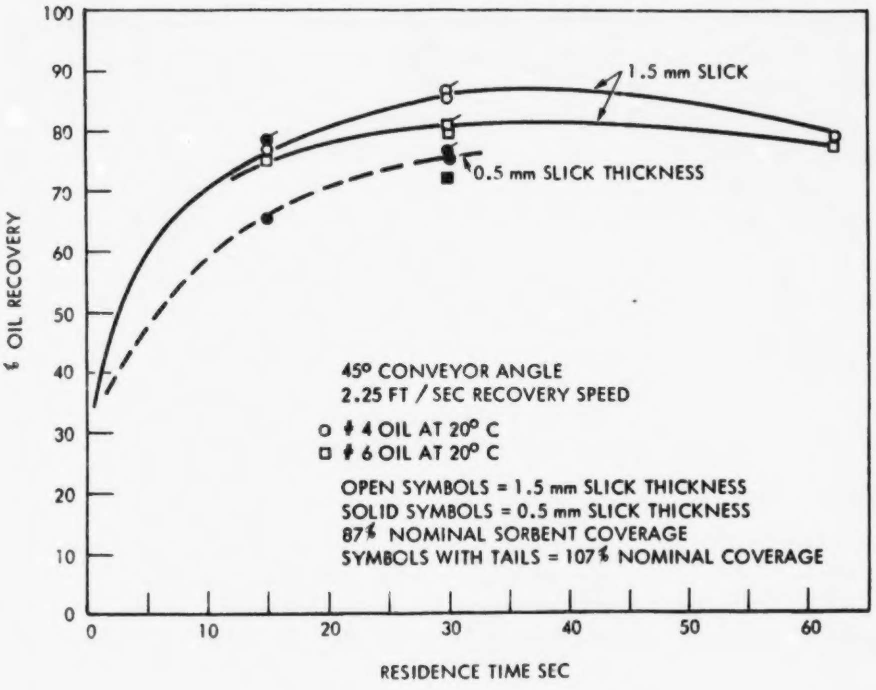


FIGURE 45 - OIL RECOVERY VS. RESIDENCE TIME (CALM WATER)

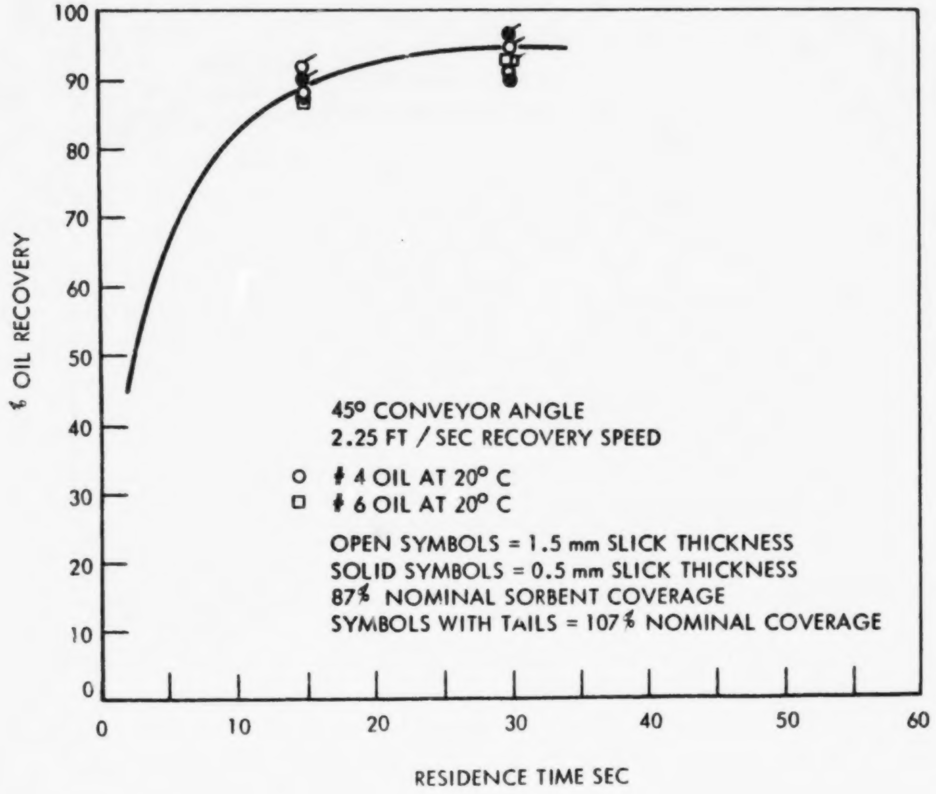


FIGURE 46 - OIL RECOVERY VS. RESIDENCE TIME (WAVES)

The percent oil recovery as a function of nominal sorbent coverage is presented in Figure 47. Data are presented for calm water and waves for residence times of 15 and 30 seconds. The nominal sorbent coverage is defined as the total projected area of the sorbent chips divided by the area of the slick. Even with a 100 percent nominal sorbent coverage, small local areas of the slick are not covered because some of the sorbent chips will overlap each other. Small waves counter this effect by moving the chips around on the surface. This wave action also reduces the required nominal sorbent coverage for maximum oil recovery. For example, Figure 47 indicates that at 30 seconds residence time in calm water, a 90 percent coverage is required for maximum oil recovery. In waves, maximum oil recovery can be obtained with between 70 and 80 percent coverage.

The basic format used in Figure 47 is suitable for synthesizing data presented in previous figures in a form convenient for system design studies. The result is a cross plot which presents percent oil recovery as a function of residence time and percent sorbent coverage. Several plots of this type could be constructed to cover the range of oil viscosity and slick thicknesses of interest. An example is presented in Figure 48. This figure presents percent oil recovery in waves and is appropriate for slick thickness from 0.5 mm to 3 mm and oil viscosities less than or equal to 6000 cm^2/sec.

Previous figures (42 and 44) presented data on the percent of oil in the recovered fluid. It was observed in the tests that the water recovered was from two sources. Some of the water is absorbed in the sorbent along with the oil or remains on the surface of the sorbent in the form of droplets. The remainder of the water is entrained by the harvesting conveyor and sprayed onto the collected sorbent. It is important for prototype predictions to separate these two sources of recovered water since the first is a function of the amount of sorbent and the second is a function of the width and speed of the harvesting conveyor. Figure 49 presents data on the water recovered which is absorbed in the sorbent material itself. These data are scattered but do indicate that high viscosity oil in the sorbent tends to reduce the amount of water recovered. The agitation of small waves tends to increase the amount of water recovered. There is no consistent indication that more water is recovered by the sorbent in thin slicks (0.5 mm) than in thicker slicks (1.5 mm). Figure 50 presents data on the rate at which the

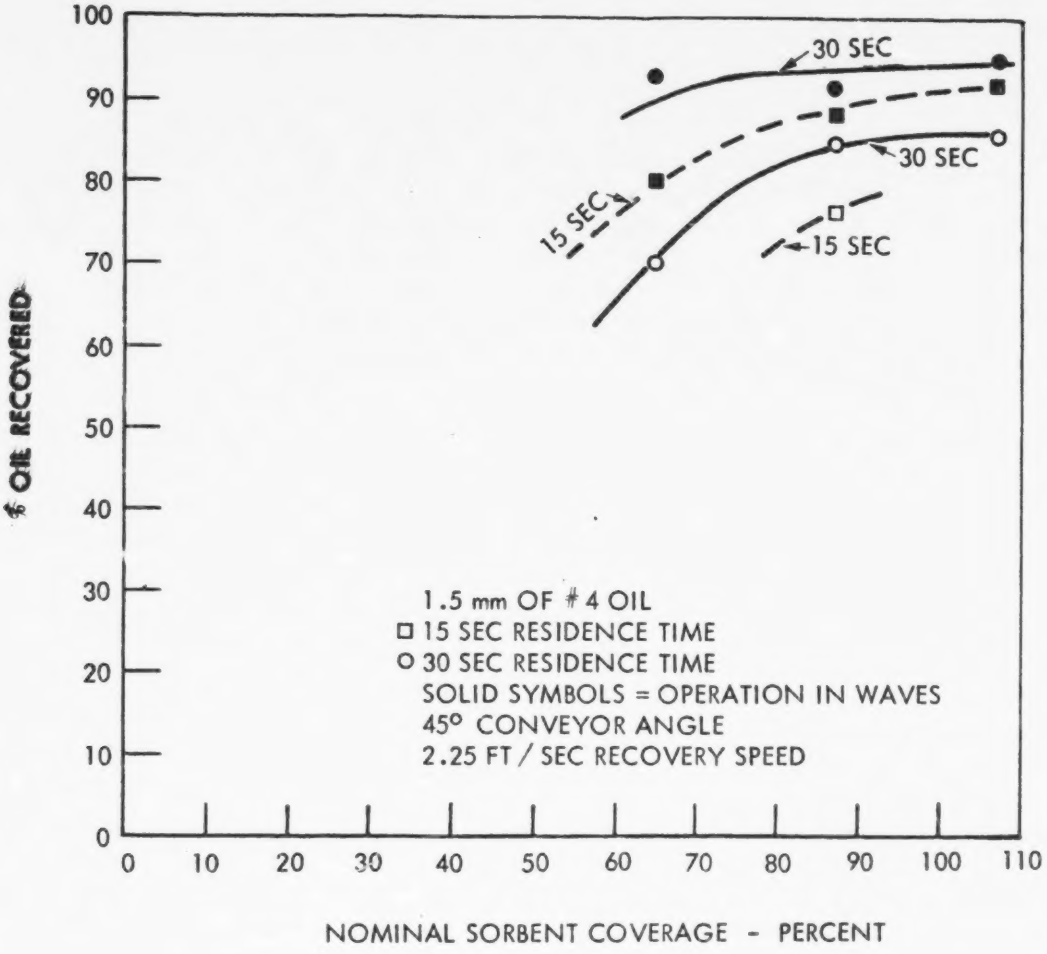


FIGURE 47 - OIL RECOVERY VS. NOMINAL SORBENT COVERAGE

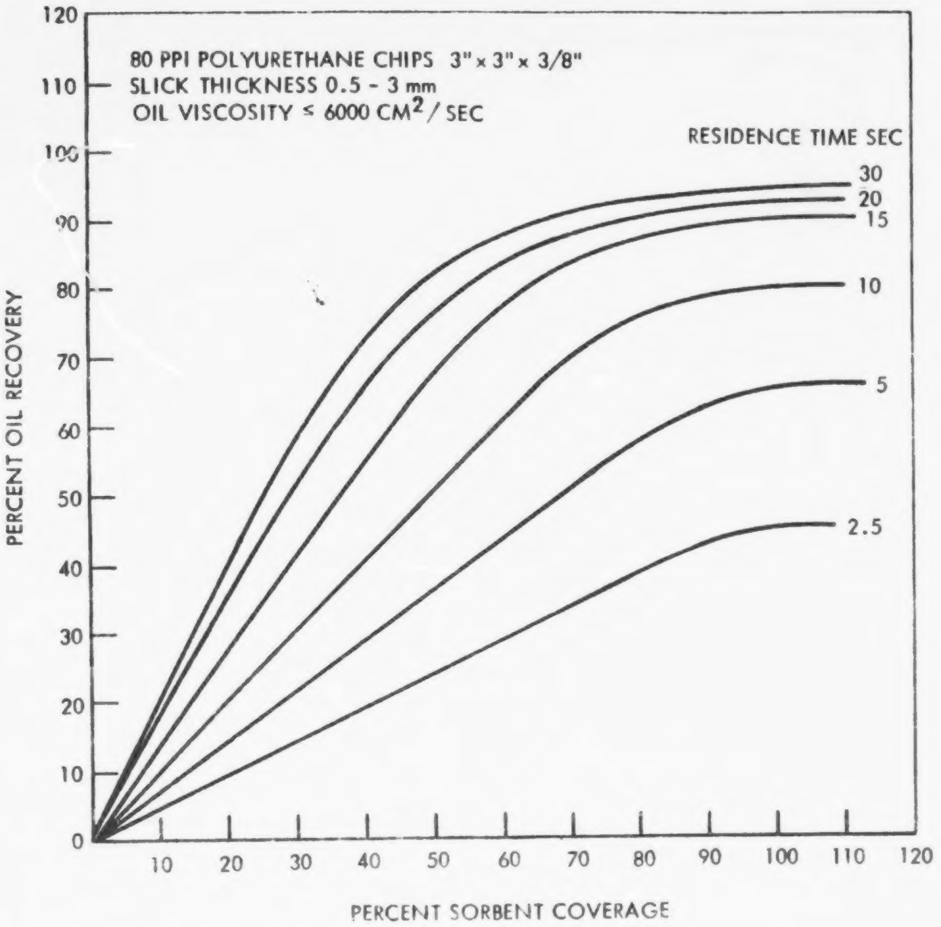


FIGURE 48 - SORBENT OIL RECOVERY PERFORMANCE IN WAVES

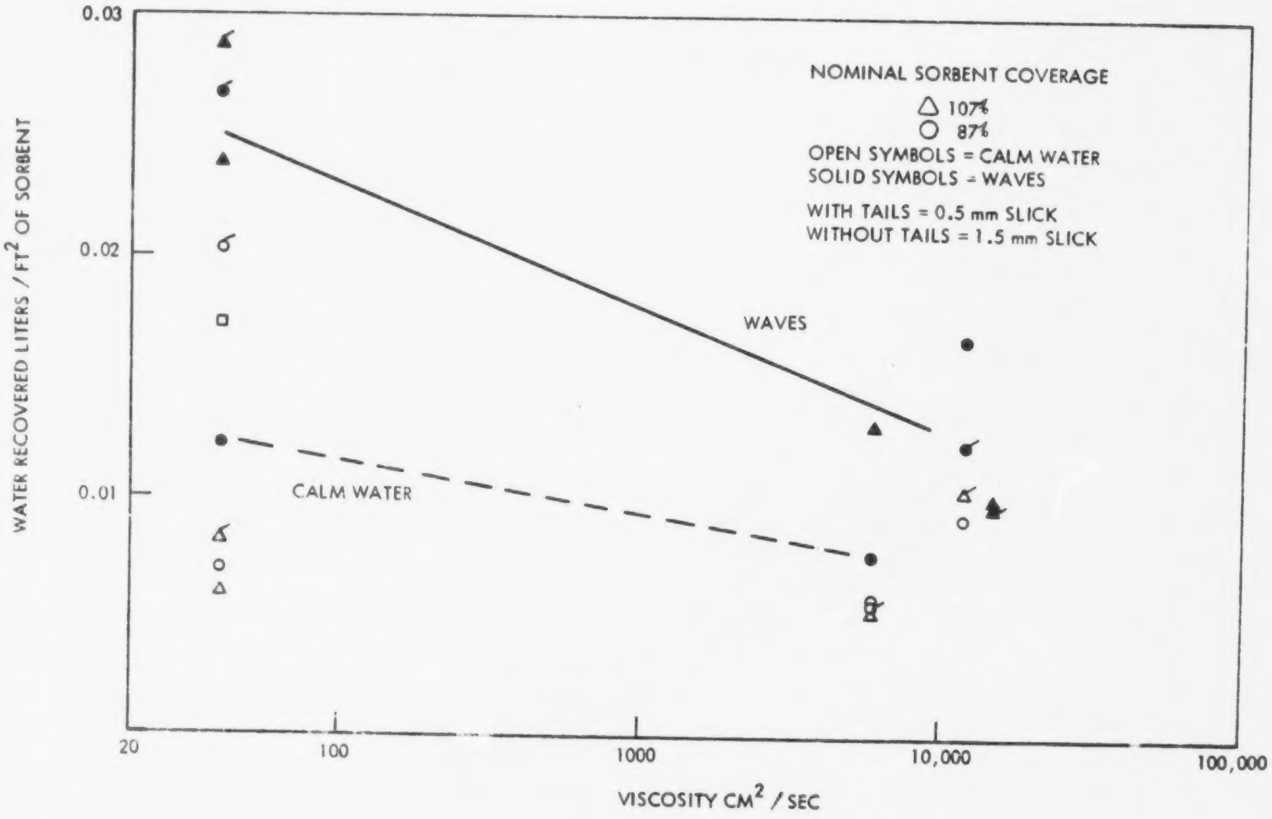


FIGURE 49 - WATER RECOVERED BY SORBENT VS. SLICK VISCOSITY

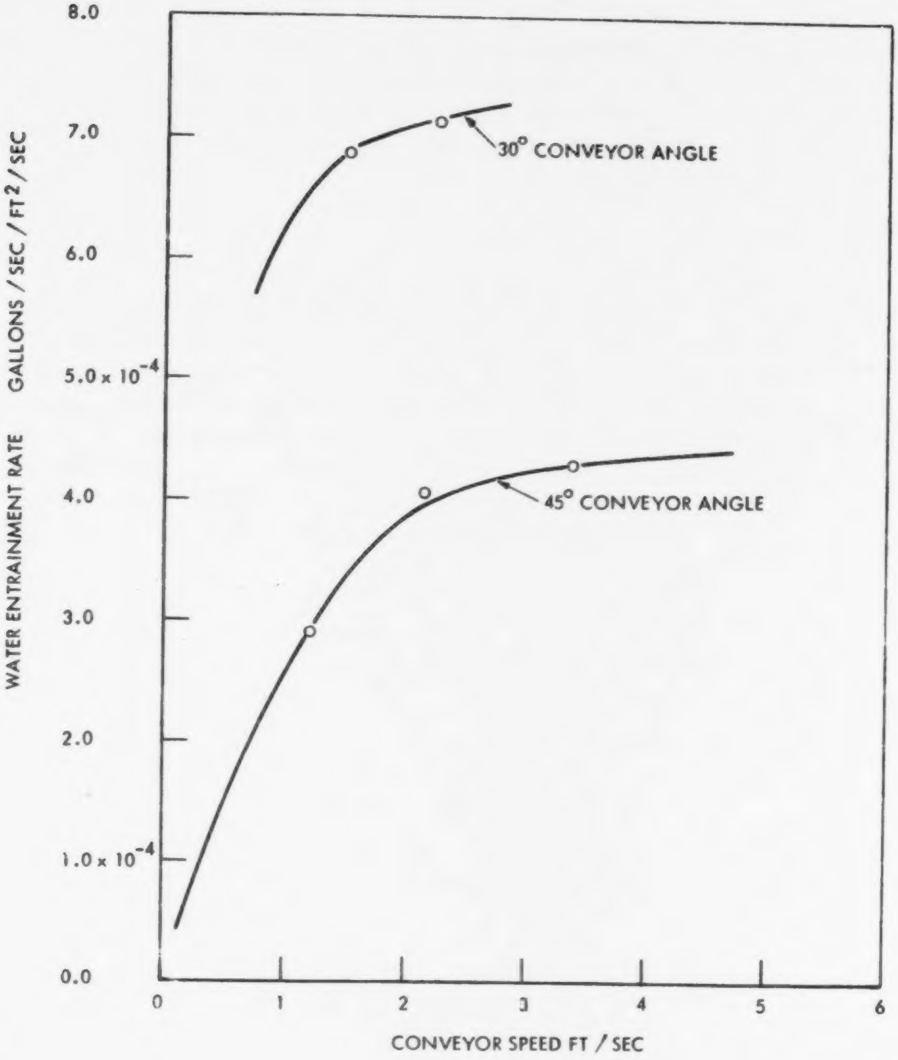


FIGURE 50 - WATER ENTRAINMENT RATE DUE TO CONVEYOR VS. CONVEYOR SPEED

harvesting conveyor entrains water and sprays it as droplets onto the collected sorbent. It should be noted that this rate is greatly reduced by increasing the conveyor angle to 45 degrees. This is a major reason for selecting as steep a conveyor angle as possible.

Summary

As a result of the work carried out under this task an optimum conveyor angle and speed ratio has been selected and the data necessary to predict the performance of the system under a wide range of conditions have been collected and analyzed. These data indicate that the oil recovery can range from 90 to 95 percent over a wide range of oil types and slick thicknesses. The percent oil in the recovered fluid will meet the EPA goal of 90 percent for slick thicknesses of 1.5 mm.

APPENDIX D

SORBENT REGENERATION SYSTEM DEVELOPMENT

The objectives of this task were:

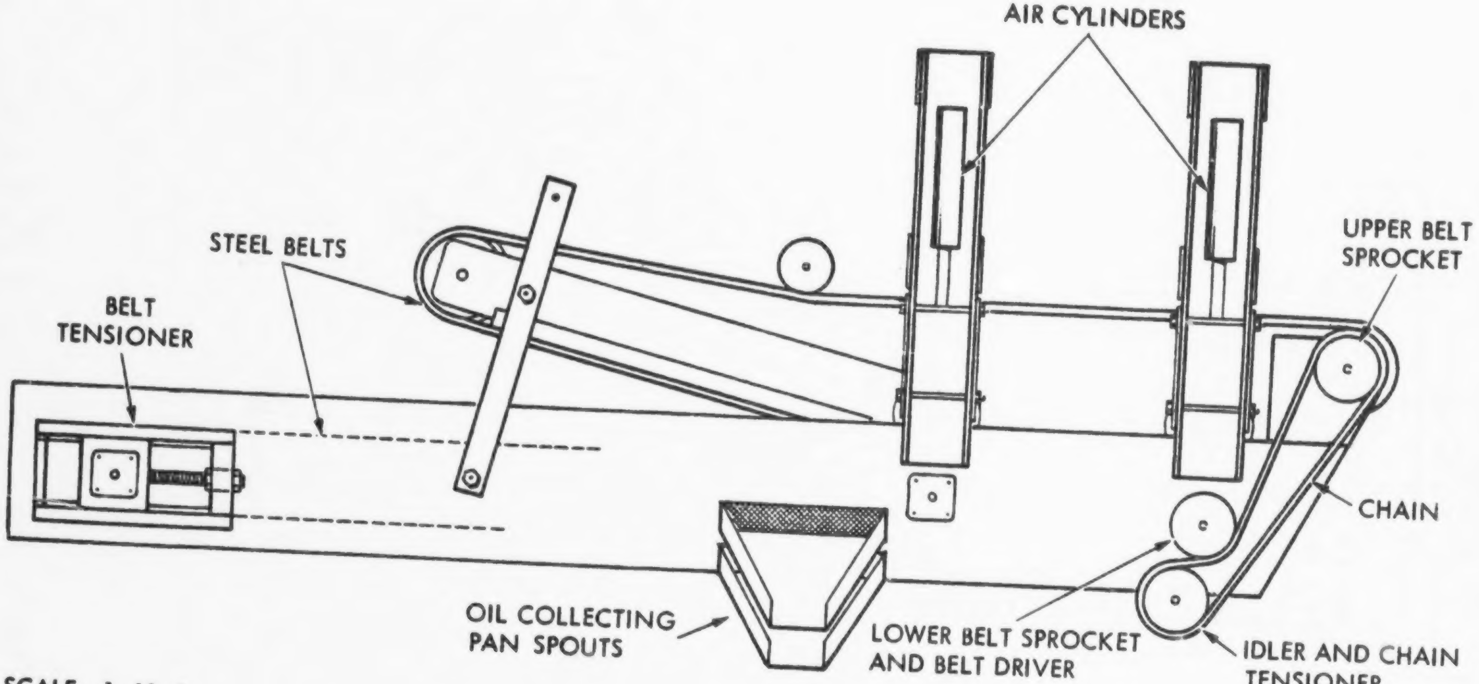
- Develop performance data for a converging belt-type sorbent regenerator as a function of the design parameters.
- Determine the effects of repeated cycles on the sorbent material.
- Identify and resolve mechanical problems prior to the construction of a prototype system.

These objectives were satisfied by designing, building and conducting tests with a sorbent regenerator test apparatus. The function of the sorbent regenerator is to squeeze the recovered oil out of the sorbent chips so that the chips are ready for broadcasting. In a typical case using 3 in. by 3 in. x 1/4 in. sorbent chips, a cubic foot of sorbent material will recover about 2 gallons of oil. The sorbent regenerator must remove the oil from the sorbent and maintain the density of the sorbent at a low enough value for broadcasting. Thus the performance of the sorbent regenerator can be defined in terms of the density of the regenerated sorbent after the removal of 2 gallons of oil per cubic foot. The parameters which influence the density of the regenerated sorbent are:

- Squeezing Force
- Oil Viscosity
- Sorbent Loading
- Sorbent Type
- Belt Speed

Test Apparatus and Procedures

A converging belt sorbent regenerator test apparatus was designed and built. Figure 51 shows an outline drawing of this apparatus and Figure 52 shows a photograph of it set up for testing. The test apparatus consists of two 18-inch wide converging conveyor belts which run between two pairs of squeezing rollers. The lower belt is an open steel mesh


AIR CYLINDERS
STEEL BELTS
BELT TENSIONER
UPPER BELT SPROCKET
CHAIN
OIL COLLECTING PAN SPOUTS
LOWER BELT SPROCKET AND BELT DRIVER
IDLER AND CHAIN TENSIONER

SCALE 1:11.4

FIGURE 51 - SORBENT REGENERATOR TEST APPARATUS

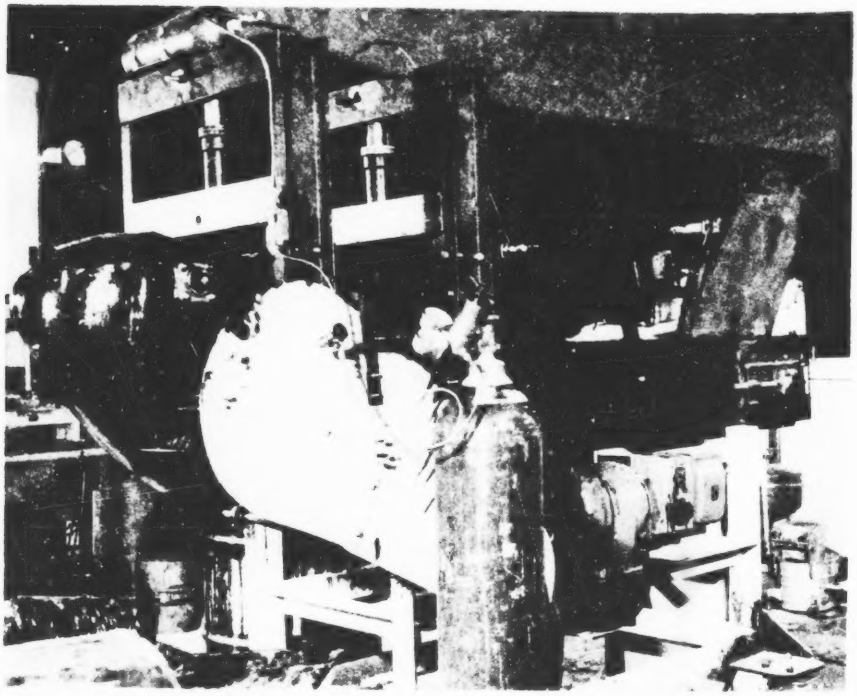


FIGURE 52 - SORBENT REGENERATOR TEST APPARATUS SET-UP

(Type B-60-32-14 Balanced Belting) and the upper belt is a similar material covered with segmented neoprene pads. The two belts are driven by a chain drive system in which the speed can be adjusted by changing sprocket size. The squeezing pressure is applied to the upper roller in each pair by an air cylinder acting through a yoke. The squeezing pressure can thus be adjusted by simply adjusting the air pressure. Oil collecting pans are located under both legs of the lower belt. The recovered oil flows by gravity out of the collecting pan spouts to a storage barrel.

In order to avoid scaling problems with the data and to identify mechanical problems, the test apparatus was designed to be near full scale for the 3000 GPH recovery unit. It is intended to scale the system up for the 10,000 GPH unit by simply making it wider.

The tests were conducted by taking a known volume of sorbent material and saturating it with between 1.5 and 2 gallons of oil per cubic foot. The sorbent was then run through the regenerator and its density determined by weighing. This process was repeated until the density of the regenerated chips reached an equilibrium value. The tests were conducted for a range of belt speeds, squeezing force, oil type, sorbent type and sorbent loading. The sorbent loading is defined as the volume of sorbent per unit belt area and has the dimensions of feet. The sorbent loading times the belt width times the belt speed gives the sorbent regeneration rate in cubic feet/second. The effect of more than two pairs of squeezing rollers was simulated by quickly recycling the regenerated sorbent.

Preliminary bench tests, during the design phase, indicated that a squeezing force of 50 pounds per inch of belt width would be satisfactory. However, preliminary testing showed that this was not sufficient to reduce the sorbent density to the desired range (i.e. 5 to 7 lbs/ft^3). As a result it was necessary to increase the shaft diameters on the squeezing rollers to allow testing at higher forces.

System Performance

The performance of a converging belt sorbent regenerator, in terms of the density of the regenerated sorbent, is presented in Figure 53 thru 55 as a function of the test parameters.

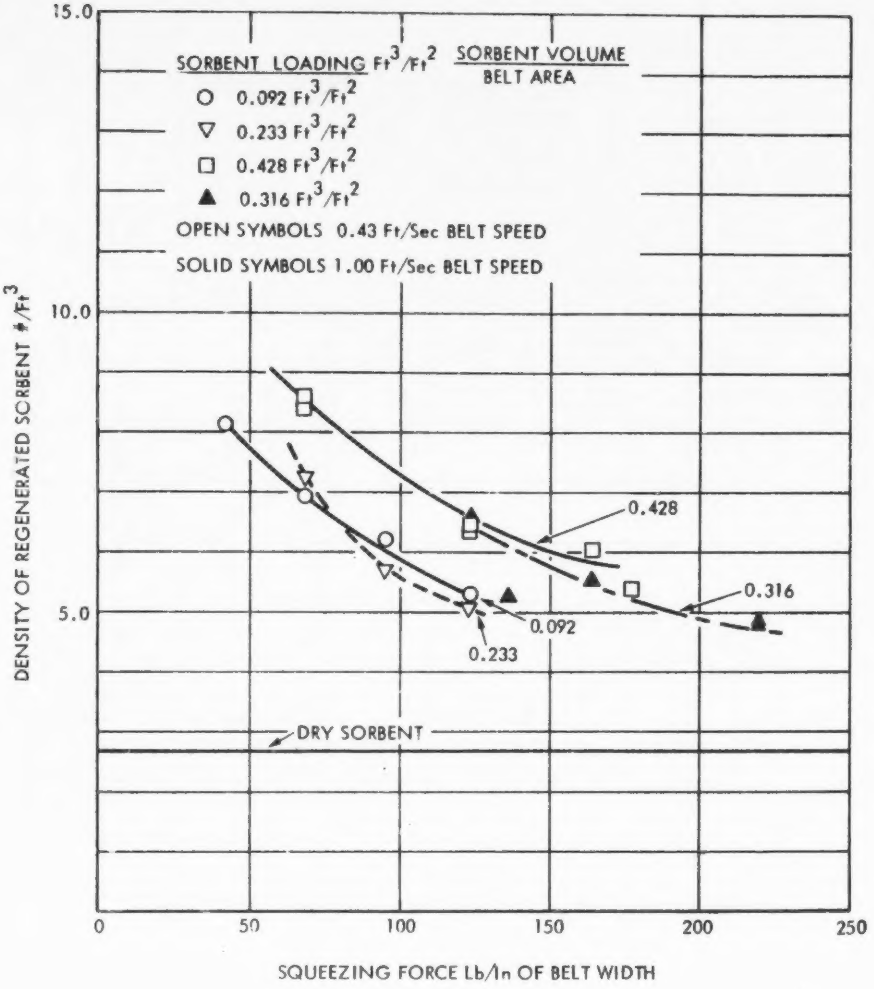


FIGURE 53 - REGENERATED SORBENT DENSITY VS. SQUEEZING FORCE (80 PPI FOAM) NO. 2 HEATING OIL

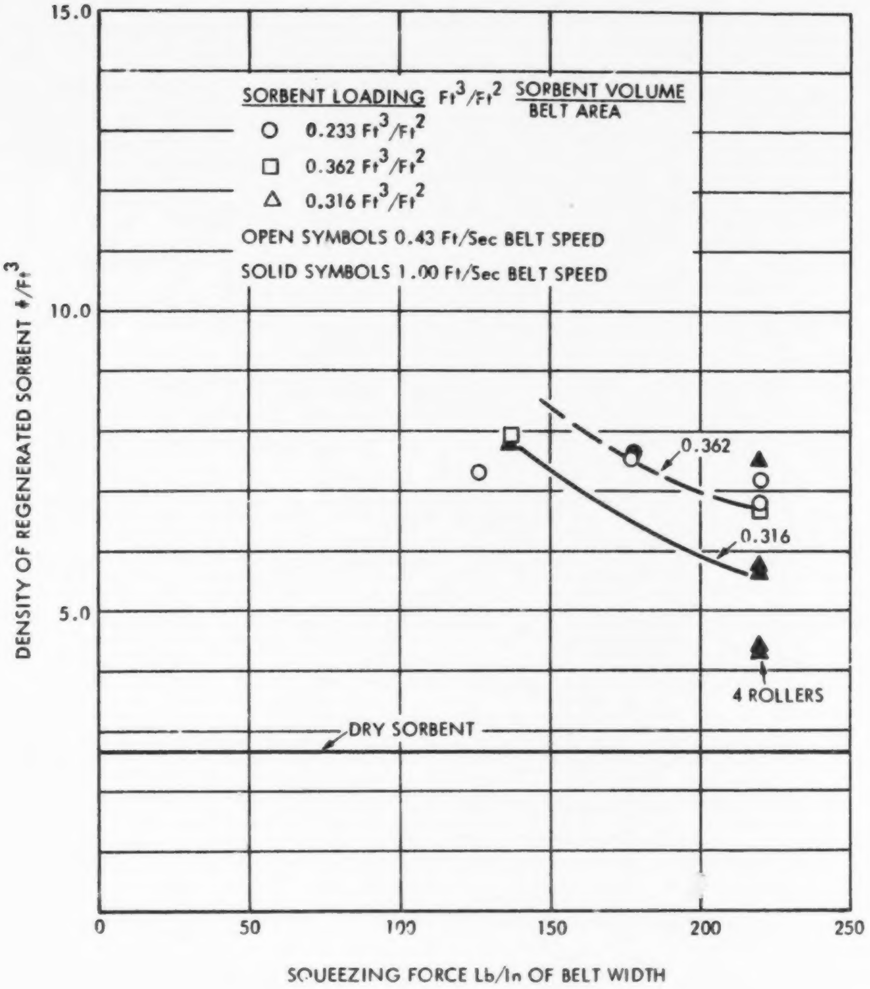


FIGURE 54 - REGENERATED SORBENT DENSITY VS. SQUEEZING FORCE (80 PPI FOAM) OIL - 70 PERCENT BUNKER "C" - 30 PERCENT NO. 2

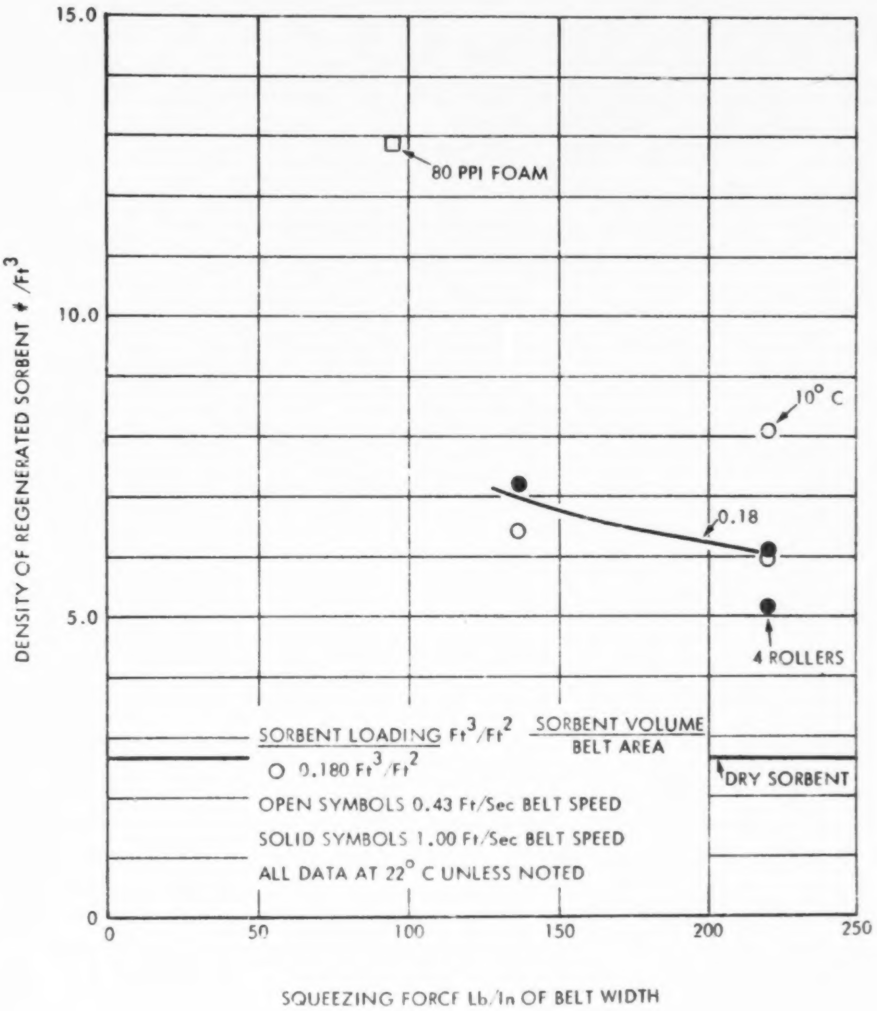


FIGURE 55 - REGENERATED SORBENT DENSITY VS. SQUEEZING FORCE (30 PPI FOAM) BUNKER "C"

Figure 53 is for 80 PPI foam and No. 2 heating oil. Figure 54 is for 80 PPI foam and an oil product made by mixing 70 percent Bunker "C" and 30 percent No. 2 heating oil. Figure 55 is for Bunker "C" and presents points for both 80 and 30 PPI foam. The viscosities of the oil products used, as a function of temperature, are given in Table 36. These figures indicate that the density of the regenerated sorbent is most sensitive to squeezing force, oil viscosity and sorbent type (80 or 30 PPI). The sorbent loading also has a significant effect on the density. The results were basically insensitive to belt speed in the range from 0.4 to 1.0 ft/sec.

TABLE 36

Viscosity of Test Oil Products

Temperature degrees, C	Viscosity: Centipoise		
	No. 2	30 percent No. 2 70 percent Bunker "C"	Bunker C
30	2.2	120	2120
20	2.6	800	4500
10	3.2	2300	20000
5	4.0	12000	153000

Figure 56 presents a summary of regenerator performance as a function of oil viscosity for a typical design point. The design point parameters are a squeezing force of 220 lb/in. a sorbent loading of 0.25 ft^3/ft^2 and a belt speed of 1.0 ft/sec or less. This figure shows the need for using 30 PPI foam when dealing with oil viscosities in excess of 1000 cps. At this squeezing force it is possible to regenerate sorbent which contains oil with viscosities up to 20,000 cps. However, the density of the regenerated sorbent increases above the desired level and heating will be required to get satisfactory flow in the oil collecting pans. Figure 56 also illustrates the benefits of increasing the number of squeezing rollers.

Mechanical Details

The tests conducted with the heavy oils indicated some tendency for the sorbent chips to stick to the lower belt and to be carried into the lower collecting pan. A simple

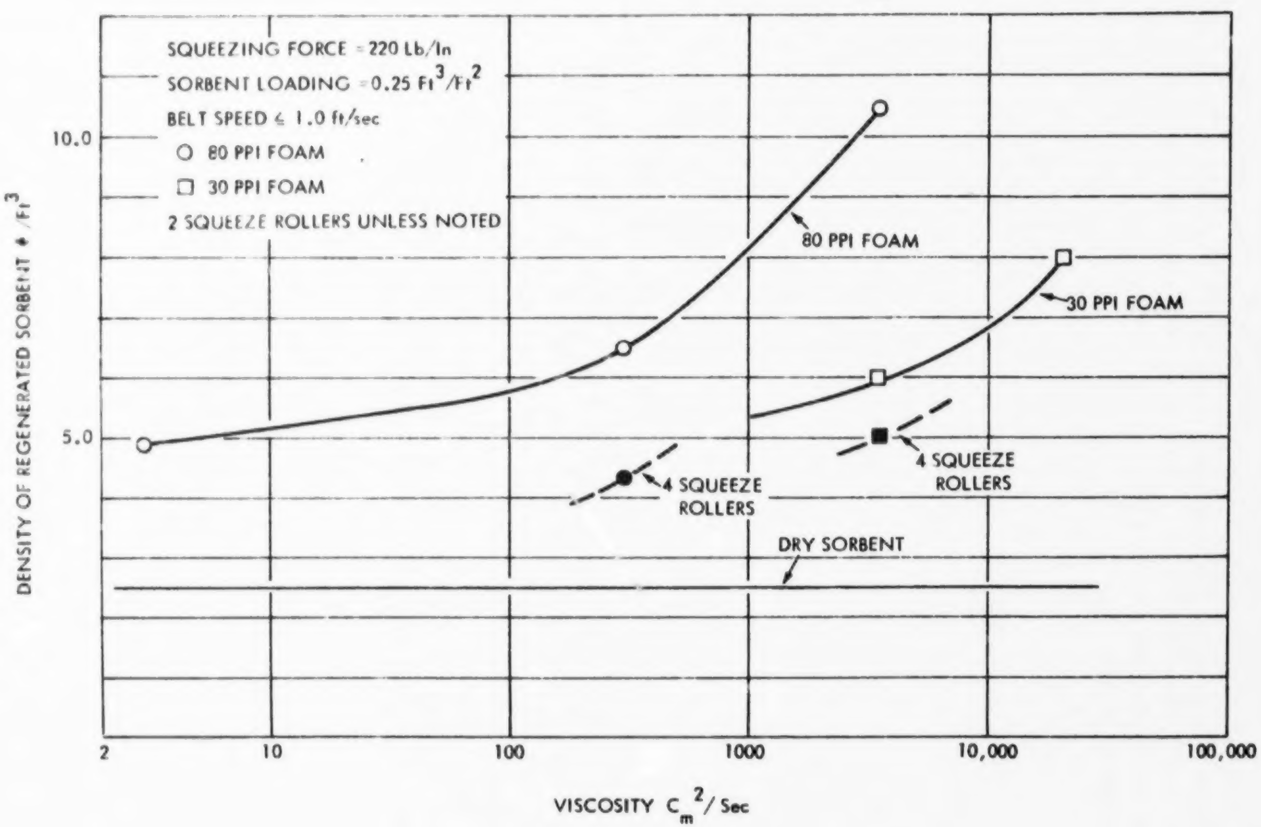


FIGURE 56 - REGENERATED SORBENT DENSITY VS. VISCOSITY

mechanical scraper is not sufficient to remove these chips. As a result, a rotating brush driven by the belt drive should be installed on the prototype. This should remove the chips without difficulty. Also, since some sorbent chips will find their way into the collecting pans, provision should be made for periodic cleaning of these pans.

It was also noted during early tests that sorbent chips were caught in the drive chains at the edges of the upper and lower belts and ultimately ground up. Simple wooden chain guards were added to the test apparatus and solved the problem. Similar guards made of a more durable material should be fitted on the prototype device.

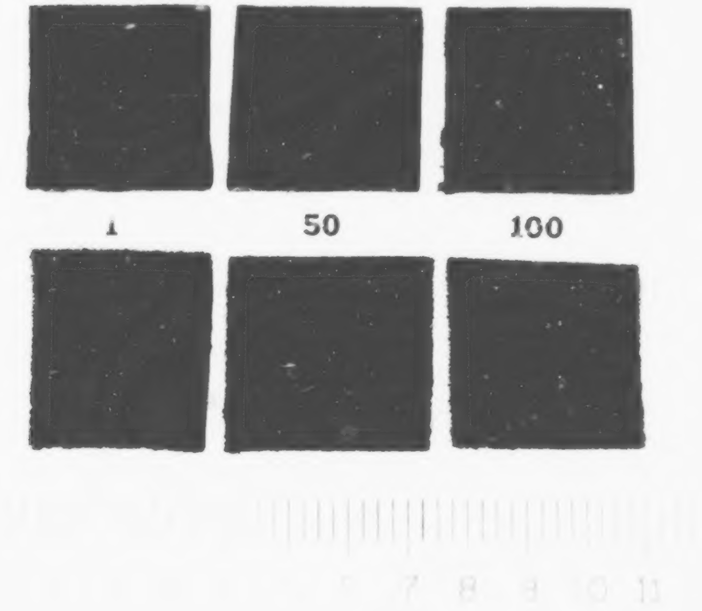
In the test apparatus the upper and lower belts were the same material and the upper belt was made solid by attaching neoprene pads to it. This will not be a satisfactory arrangement for the prototype regenerator. The upper belt should be simple reinforced neoprene belt or a wire mesh belt of the type used impregnated with neoprene.

The air cylinders used to provide the squeezing force gave excellent service and provide a simple and reliable means of applying and controlling the squeezing force. The shafts in the squeezing rollers should be designed to withstand the loads applied by a piece of drift wood or debris going through the regenerator. For the 3000 GPH unit 1-1/2 inch diameter high strength steel shafts should be satisfactory.

An endurance test was conducted to determine the effects of repeated regenerations on the sorbent material. These tests were carried out by saturating a group of chips (about 20) and running them through the sorbent regenerator test apparatus at a high enough squeezing force to reduce their density to 6 lb/ft^3. This process was repeated 100 times for 80 PPI chips using a mixture of 90 percent Bunker "C" and 30 percent No. 2 oil and for 30 PPI chips using Bunker "C". Figure 57 presents a photograph of chips that were regenerated 1, 50 and 100 times. There was no significant degradation of the sorbent chips after 100 cycles.

Results

The important results of this task can be summarized as follows:


1
50
100
7
8
9
10
11

Heavy numbers indicate the number of times sample sorbent chips were regenerated

FIGURE 57 – SORBENT CHIPS AFTER ENDURANCE TEST

- A converging belt sorbent regenerator will satisfactorily regenerate sorbent chips at the volume rates required.

- The density of the regenerated chips will be about 6 lb/ft^3 for a squeezing force of 220 lb/in. a sorbent loading of 0.25 ft^3/ft^2 and a belt speed of 1 ft/sec.

- In order to maintain a 6 lb/ft^3 regenerated sorbent density, 30 PPI foam should be used for oil viscosities in excess of 1000 cps.

- An oil viscosity of about 20,000 cps at the time of regeneration is the practical upper limit because of the excessive density of the regenerated sorbent.

- The sorbent material can be cycled 100 times without significant degradation.

APPENDIX E

MODEL TEST OF A 1/4-SCALE MODEL RECOVERY PLATFORM

The objectives of this task were:

1. Demonstrate that a continuous stable sorbent broadcast and recovery cycle is possible.

2. Determine any adverse effects of waves and forward speed on the continuous broadcast and recovery cycle.

3. Determine the towing resistance and stability of the recovery platform at the deployment and operating draft.

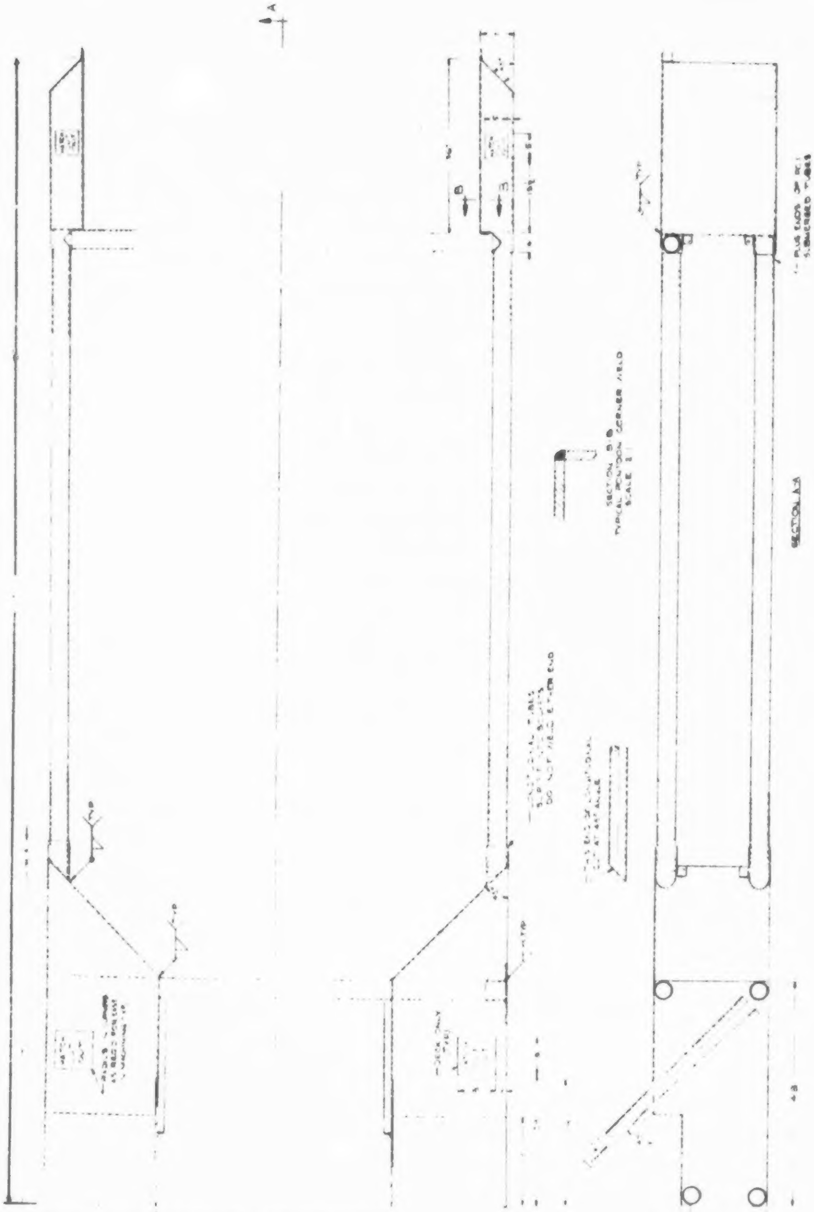
The objectives of this task were carried out by means of tests on a 1/4 scale model of the recovery platform in the HYDRONAUTICS Ship Model Basin, (HSMB®). The model was equipped with an operating broadcasting system and harvesting conveyor. No squeezing system was fitted so no attempt was made to actually recover oil.

The most important results of the test program were the qualitative observations with respect to the feasibility of a continuous, stable, broadcasting and recovery cycle under different operating conditions. Quantitative data were obtained on the towing resistance of the recovery platform under different conditions. A description of the model, the test procedure and the results are presented in the following paragraphs.

Description of Model and Test Facilities

The basic concept for the recovery platform was developed in the original HYDRONAUTICS, Incorporated Sorbent Oil Recovery System Proposal. Subsequently, preliminary efforts showed that the basic concept and general proportions were still valid. As a result, the model design was based on the original concept and was sized to be a 1/4 scale model of a system intended to recover 10,000 gallons per hour.

A 1/4 scale aluminum model of the recovery platform equipped with an operating sorbent broadcasting and recovery system was constructed. Figure 58 presents an arrangement drawing for the model with its dimensions.


SECTION A-A
PONTOON ASSEMBLY

58 - OIL SORBENT RECOVERY SYSTEM; PONTOON ASSEMBLY

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The broadcasting system on the model was based on the work reported in Appendix B. The movable parallel plate nozzle was a scaled down version of the one tested in Task 2, and equipped with a simple mechanical drive. No attempt was made to scale the actual blower. Rather, the blower available from the small scale experiments conducted under Task 2 was used. The air flow necessary for good sorbent distribution was obtained by choking the blower inlet.

The harvesting conveyor angle of 45 degrees was based on the results of Task 3. It was not practical to obtain a conveyor belt material that was a 1/4 scale model of that used in Task 3. However, it was felt that this was not important. Instead, a light weight wire belt with 1/4 inch high wooden flights was used. The harvesting conveyor was driven with a variable speed drive so that the linear conveyor speed could be adjusted to equal the towing speed of the platform. A transfer conveyor was fitted between the aft pontoons of the platform to collect the sorbent chips from the harvesting conveyor and feed them to the broadcasting system blower. The transfer conveyor was also fitted with a variable speed drive. Figure 59 presents photographs of the mechanical systems described above.

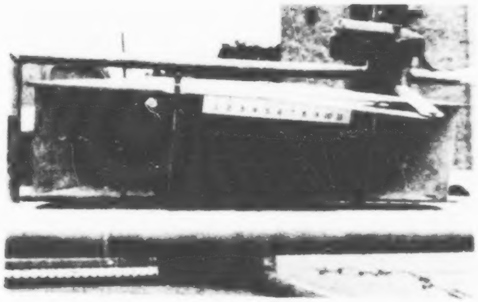
The sorbent material was simulated with a white color, closed cell foam. This foam was cut to 1/8 in. thick, 3/4 in. by 3/4 in. squares.

The tests were carried out in the HYDRONAUTICS Ship Model Basin at HYDRONAUTICS, Incorporated. This towing tank is equipped with a towing carriage with a top speed of 20 ft/sec, and with instrumentation to measure forces, motions and wave height. A plunger type wavemaker is fitted at one end of the towing tank which is capable of generating regular and long crested irregular waves. The dimensions of the towing tank are:

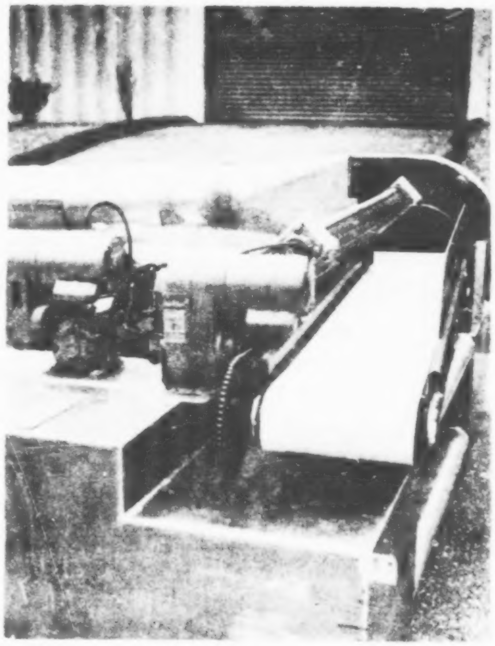
Length	308 feet
Width	25 feet
Depth	13 feet

Test Procedures

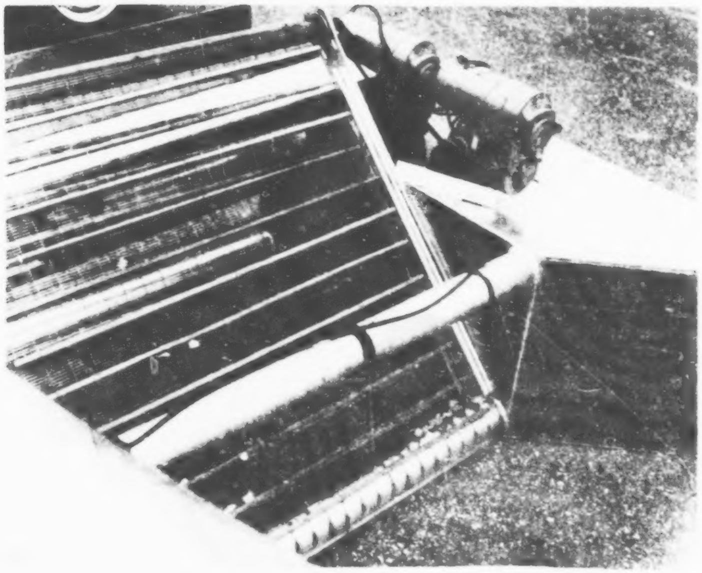
The towing tests were carried out with the model towed behind the towing carriage on about 30 feet of towline. The towline ran from a 60 degree bridle between the forward



Broadcasting Nozzle and Drive



Transfer Conveyor and Drive



Harvesting Conveyor and Drive

FIGURE 59 - MECHANICAL DETAILS OF SORBENT RECOVERY PLATFORM MODEL

pontoons, under the carriage, to a force measuring block gage mounted on a post at the forward end of the carriage. A sonic wave height probe was mounted on the forward end of the towing carriage to measure the height of the incident waves. A capacitance type wave height probe was mounted outboard on the aft port pontoon at the same longitudinal location as the lower end of the harvesting conveyor. The purpose of this probe was to measure the relative motion between the waves and the recovery platform. The outputs from the force gage and the two wave probes were recorded on paper strip charts. Also the output of the force gage was integrated to give the average drag.

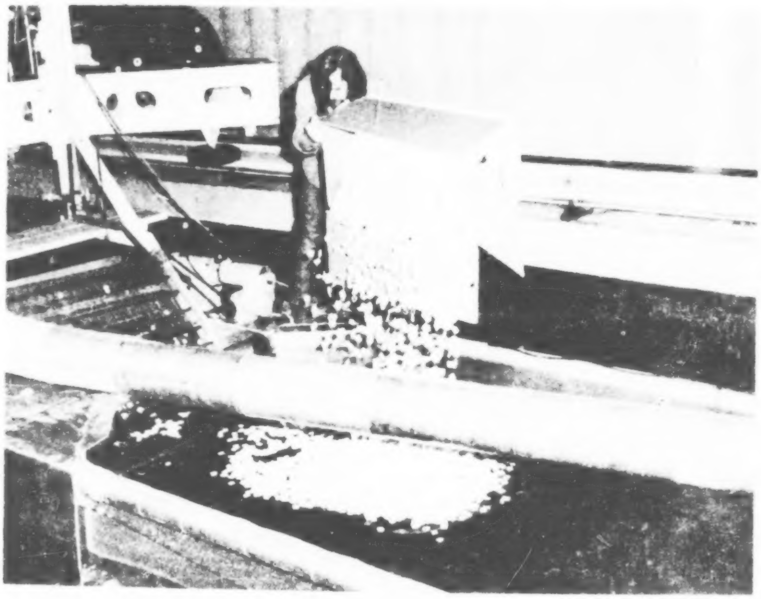
At the start of a typical test, the sorbent material chips were dumped into the center of the recovery platform, as shown in Figure 60, and the harvesting conveyor, transfer conveyor and broadcasting systems were started. The towing carriage then towed the model down the tank at the desired speed while the towing drag, wave height and relative motion were recorded. Also, pictures and observations were made of the sorbent distribution and recovery. After the first test run of the day, the sorbent material was simply allowed to remain in the recovery platform.

In addition to the towing tests, some tests were carried out with the model pushed by the towing carriage. This was to simulate the type of operation in which the recovery platform is pushed by a barge. The pushing was done with 3 foot long steel arms pivoted at both ends. In these tests, no measurements were made of pushing force. This test setup is shown in Figure 60.

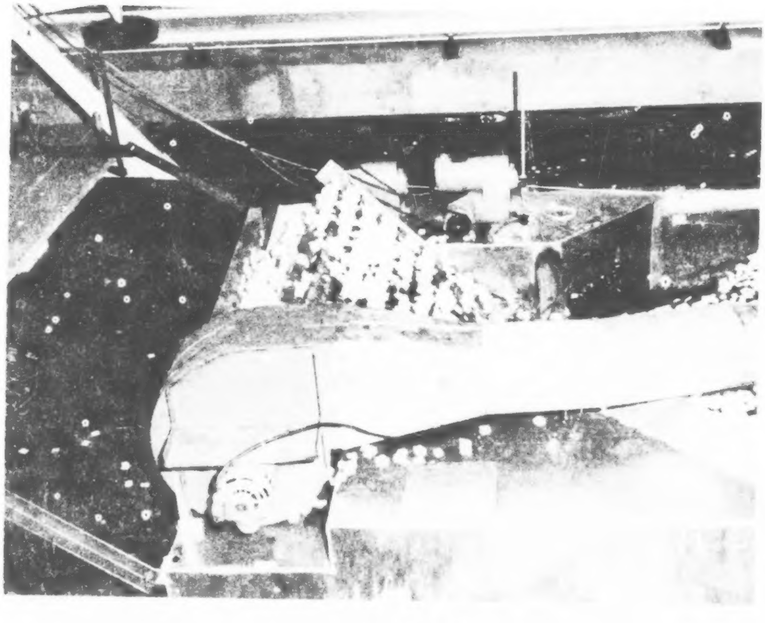
Towline Drag and Towing Stability

Towing tests of the sorbent recovery platform were carried out over a range of speeds and sea states for the deployment and nominal operating conditions. The drafts and salt water displacements for these conditions are:

Condition	Draft	Displacement
Deployment	2' - 0"	57,500 lbs
Nominal Operating	3' - 0"	80,000 lbs



Adding Sorbent Material at Start of Test



Arrangement of Pushing Arms

FIGURE 60 - TEST SETUP FOR SORBENT RECOVERY PLATFORM MODEL

Tests were conducted in long crested irregular waves corresponding to Sea State 1 (significant wave height = 1.1 ft) and a low Sea State 3 (significant wave height = 2.6 ft).

The significant wave height is defined as the average height of the 1/3 highest waves.

The towline drag data were expanded to the full scale value using Froude scaling. Because of the low scale ratio ($\lambda = 4.0$) and the bluff shape of the body, no correction was made for changes in the skin friction in expanding the drag data to full scale. The resulting towline drag for calm water and waves over the range of speeds expected for sorbent recovery are presented in Figure 61 for the deployment condition. Figure 62 presents the towline drag in calm water for the deployment condition up to the highest practical towing speed. This speed is about 9.5 knots and is limited by excessive sinkage the trim of the platform. Figure 63 presents a photograph of the model under tow at a speed equivalent to 9.5 knots. Figure 64 presents the towline drag for the nominal operating condition over the expected range of speeds for sorbent recovery in calm water and waves.

The towline drag data for calm water were also reduced to nondimensional form so that they can be used to estimate the drag of similar platforms of different size. The results are presented in Figure 65 in terms of a towline drag coefficient as a function speed length ratio. The drag coefficient is defined as:

$$C_D = \frac{D}{\frac{1}{2}\rho\nabla^{2/3}u^2}$$

where

D = towline drag, lbs

ρ = mass density of water, slug/ft^3

∇ = displaced volume of platform, ft^3, and

u = towing speed, ft/sec.

The speed length ratio is defined as:

$$\text{Speed length ratio} = \frac{V_K}{\sqrt{L}}$$

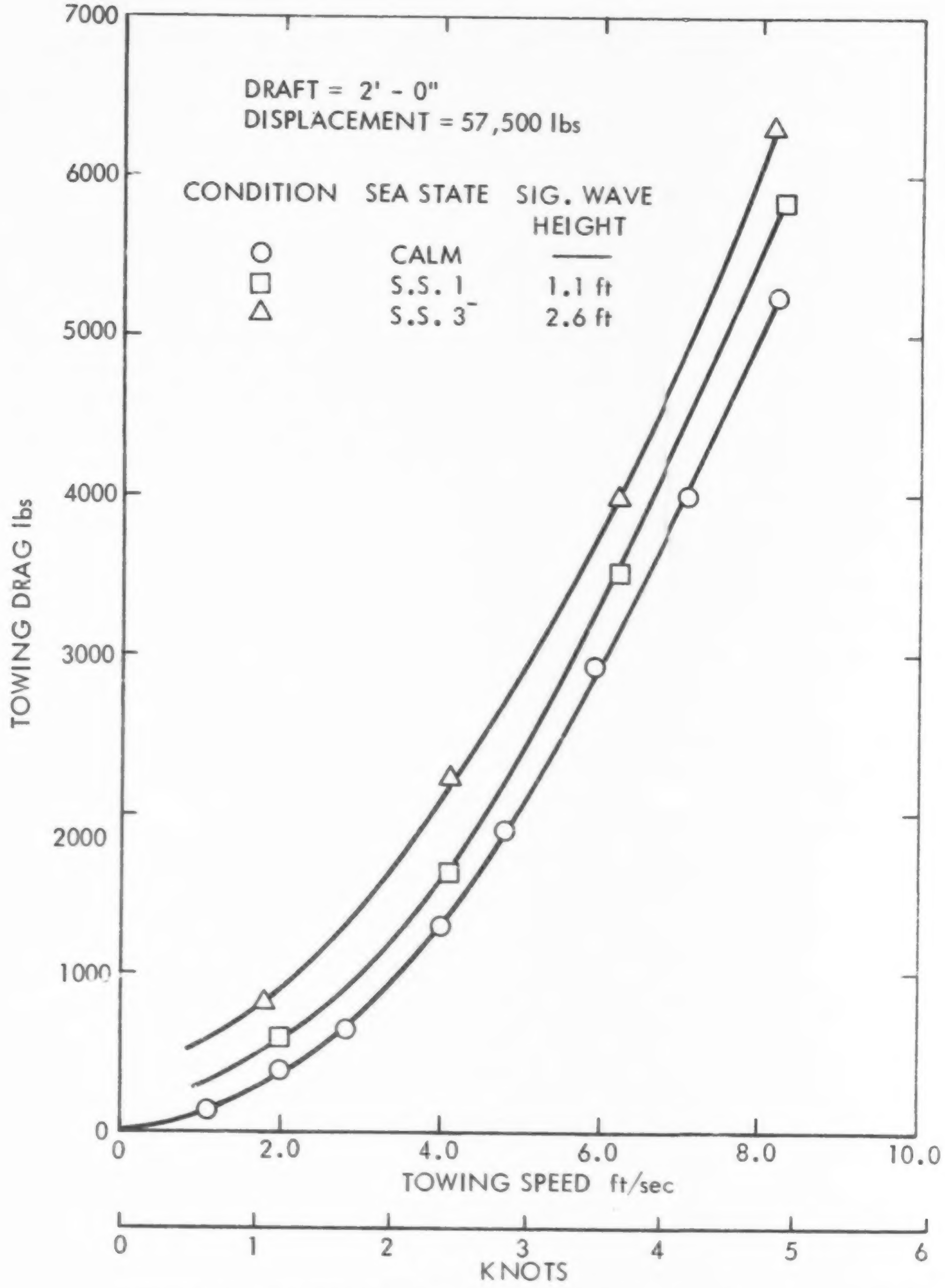


FIGURE 61 - SORBENT RECOVERY PLATFORM DEPLOYMENT DRAFT TOWLINE DRAG Vs SPEED AND SEA STATE

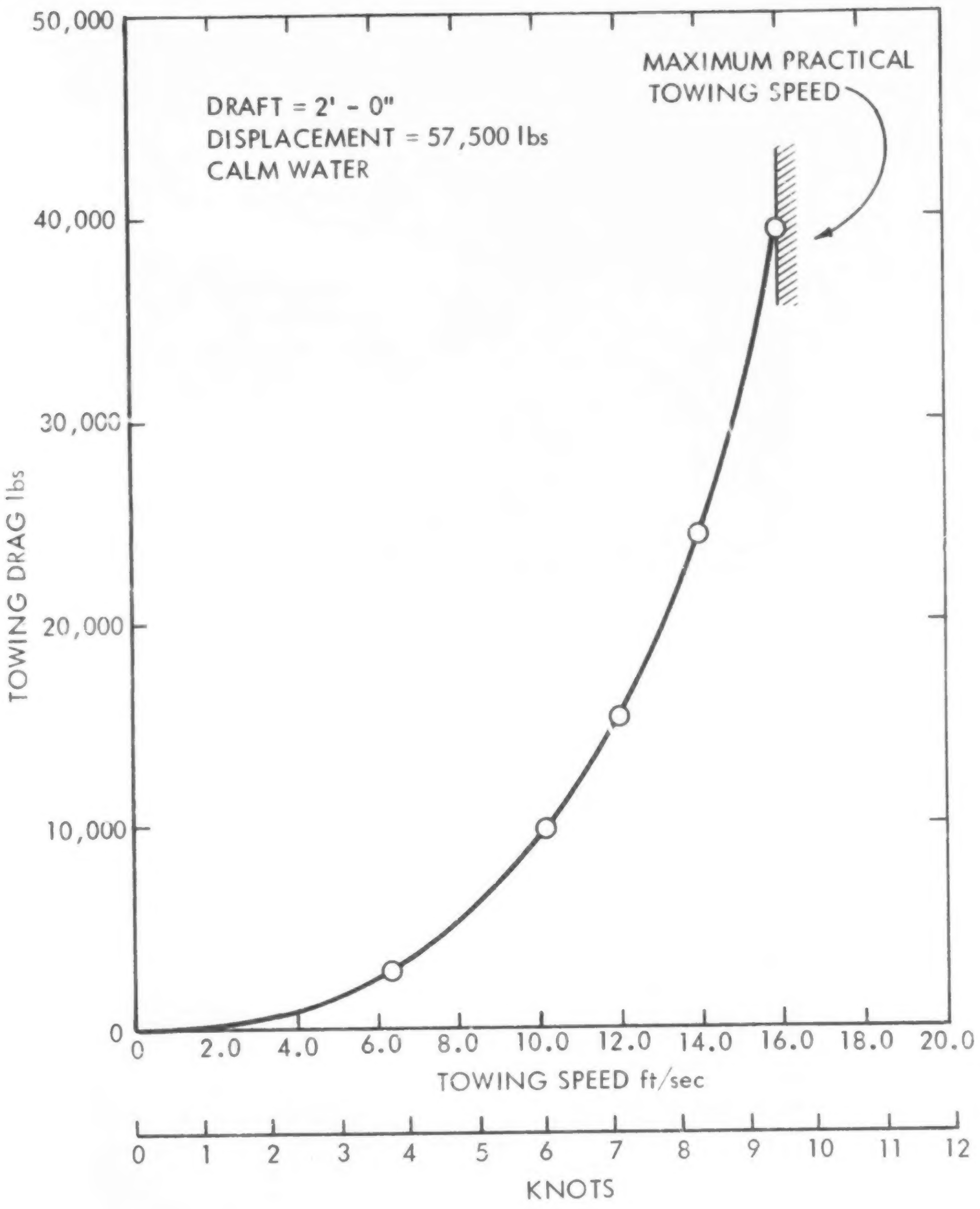


FIGURE 62 - SORBENT RECOVERY PLATFORM DEPLOYMENT DRAFT TOWLINE DRAG Vs SPEED

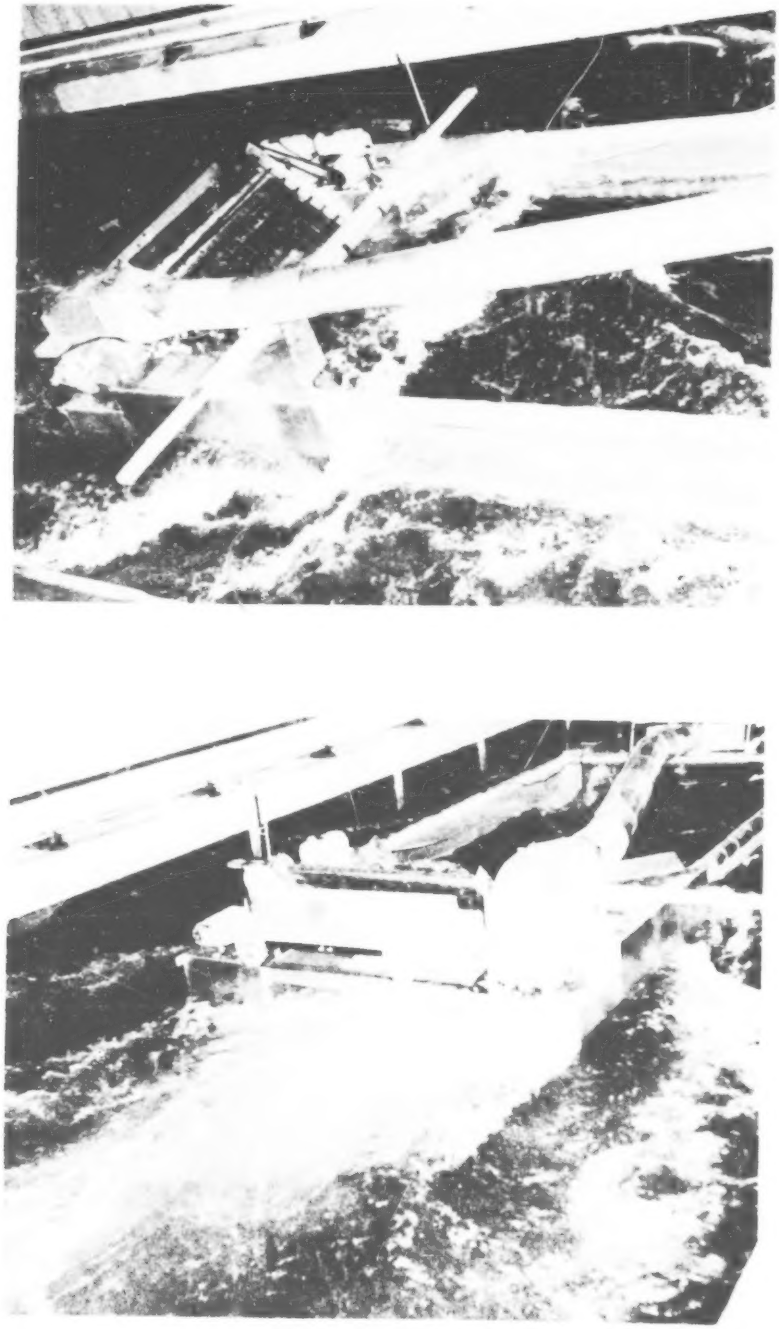


FIGURE 63 - SORBENT RECOVERY PLATFORM UNDER TOW AT 9.5 KNOTS

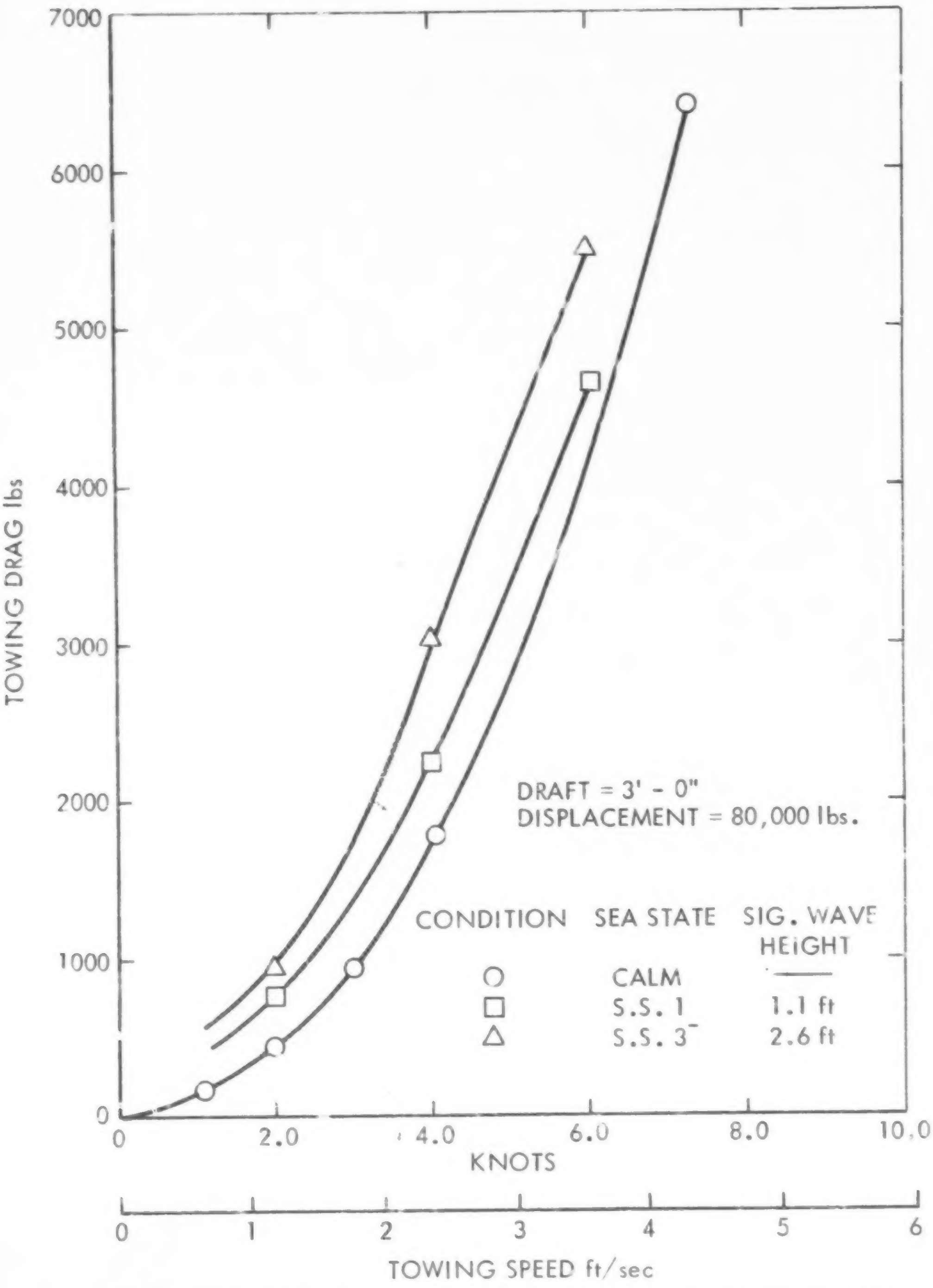


FIGURE 64 – SORBENT RECOVERY PLATFORM OPERATING DRAFT TOWLINE DRAG Vs SPEED AND SEA STATE

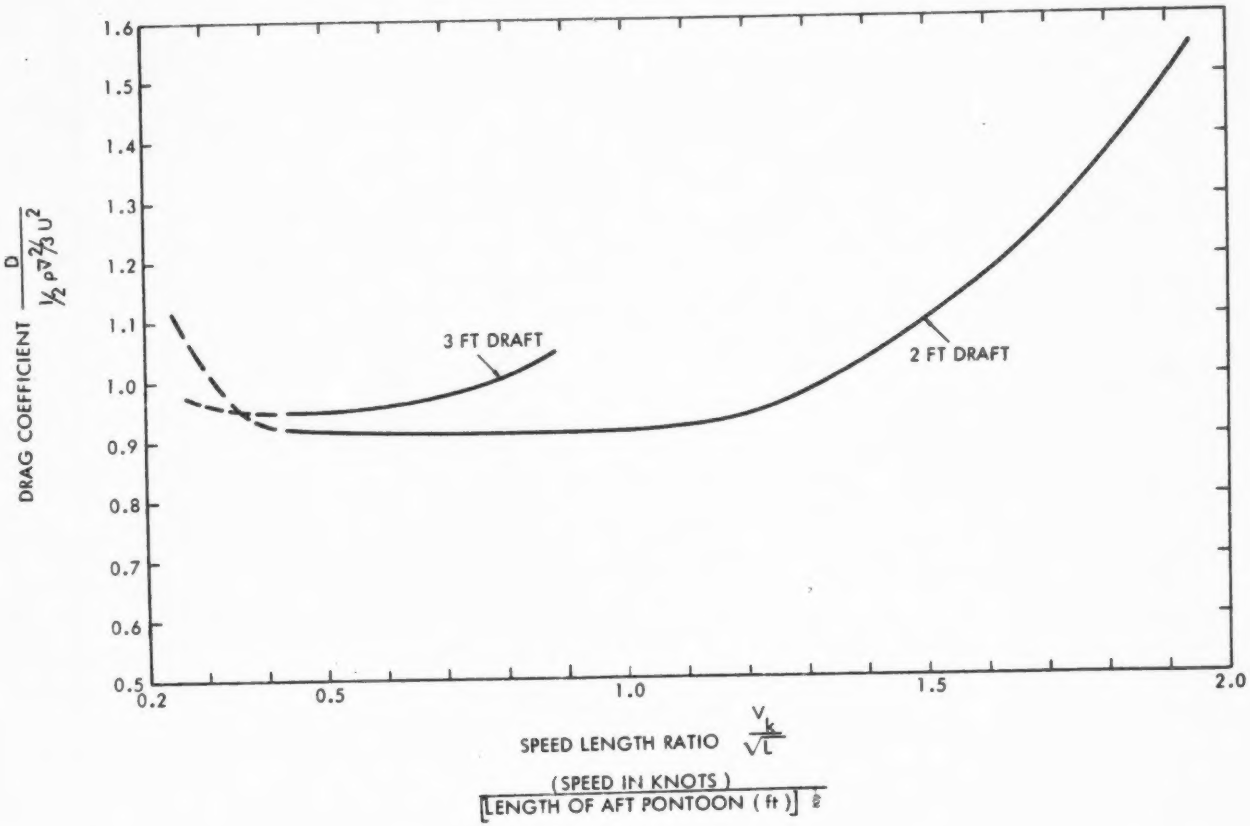


FIGURE 65 - SORBENT RECOVERY PLATFORM DRAG COEFFICIENT VS. SPEED LENGTH RATIO

where

V_K = towing speed, knots, and

L = length of aft pontoon, ft.

The length of the aft pontoon was selected for the length scale in the speed length ratio since it is the longest continuous component in the recovery platform. The rise in the drag coefficient above a speed length ratio of 1.2 indicates that energy is being dissipated in surface waves as well as in form drag.

The towing stability was checked by giving the model a lateral displacement as it was being towed down the tank. The model rapidly returned to its original position directly behind the towing point on the carriage. This indicates the platform has directional stability when under tow and thus will tow satisfactorily without yawing.

Sorbent Broadcasting and Recovery

The sorbent broadcasting and recovery tests were conducted for conditions equivalent to full-scale speeds of 3.0 and 6.0 ft/sec in calm water, Sea State 1 and a low Sea State 3. The data obtained in these tests were qualitative in nature and consisted of observations of performance supported by still and motion pictures. Typical photographs from the test program are presented in Figures 66, 67 and 68. All of the photographs are for a speed equivalent to 3 ft/sec full-scale which is the nominal design speed. The range of sea conditions from calm to a low sea state 3 are covered by the photographs. The important observations from the broadcasting and recovery tests are presented below:

1. The sorbent distribution within the system is stable. The tests showed that concentrations of sorbent material in the system tend to become spread out, and that ultimately the sorbent distribution throughout the system tends to become uniform. This is because of the broadcasting subsystem which spreads the sorbent over a substantial (about 20 feet) longitudinal distance as well as lateral distance. As a consequence of the stability of the sorbent distribution,

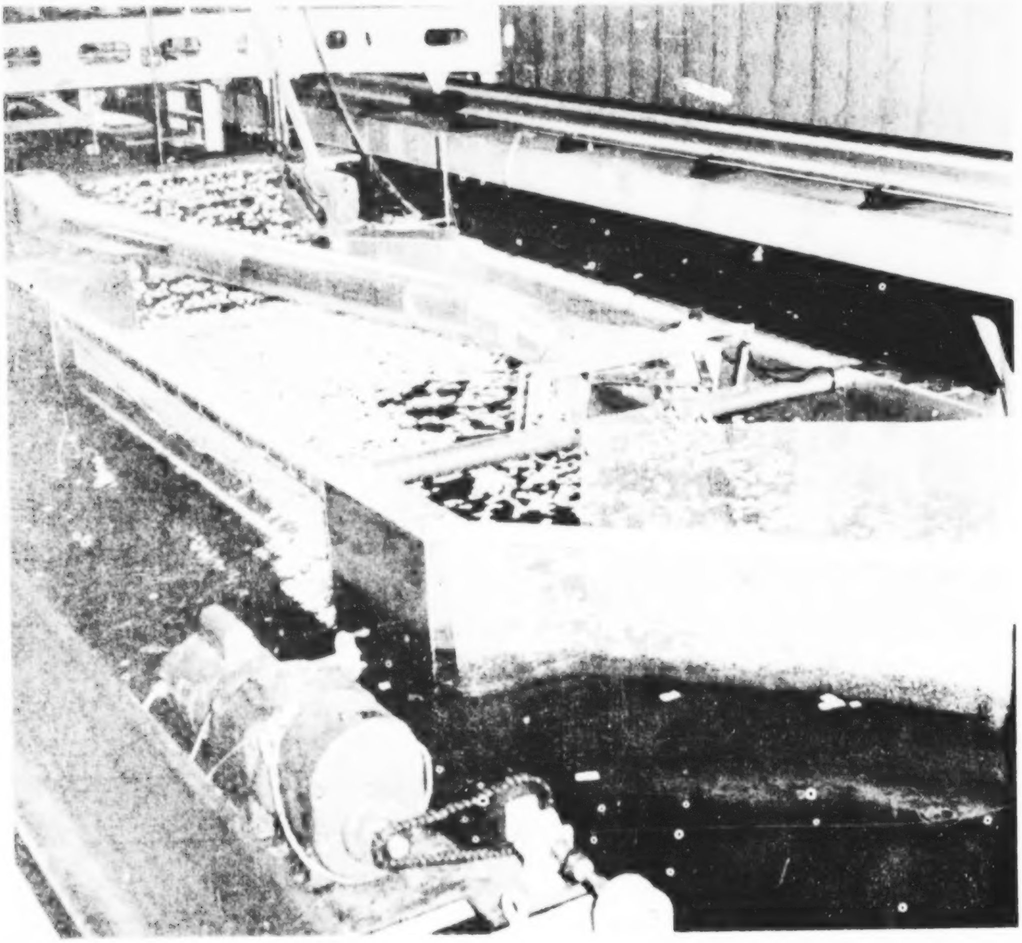
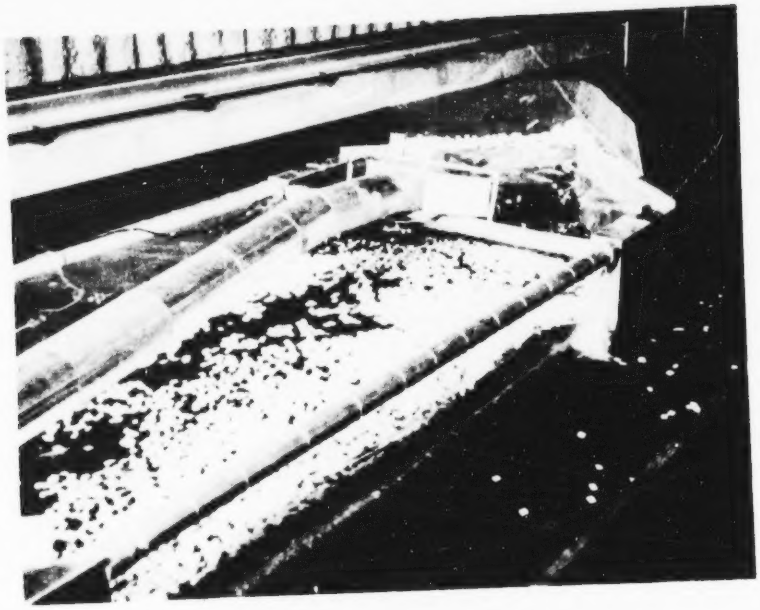
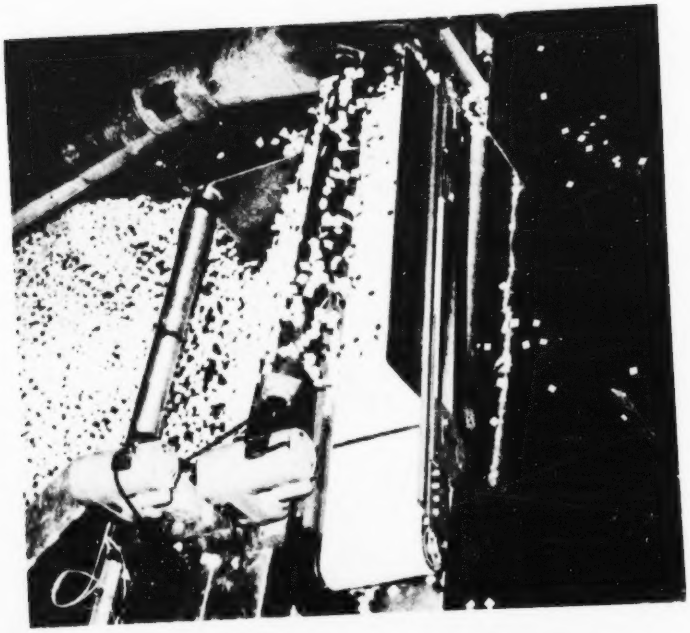


FIGURE 66 - RECOVERY PLATFORM OPERATING IN CALM WATER AT 3.0 ft/sec

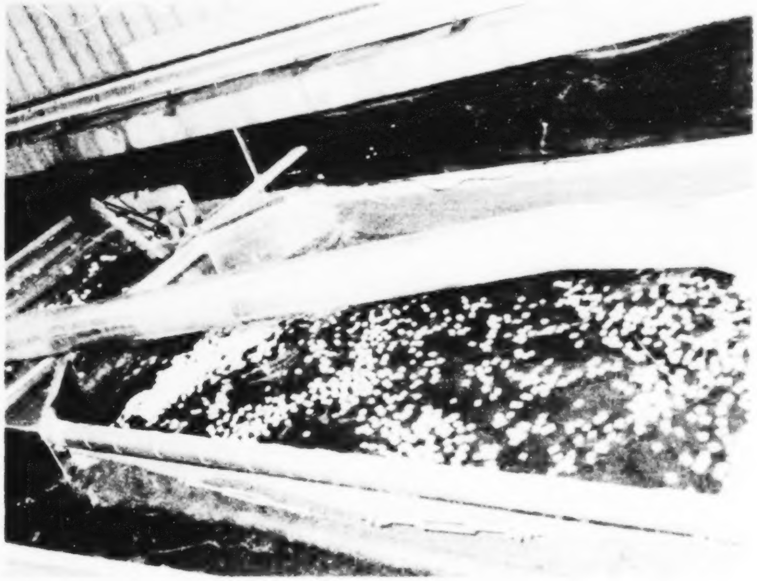


Broadcasting

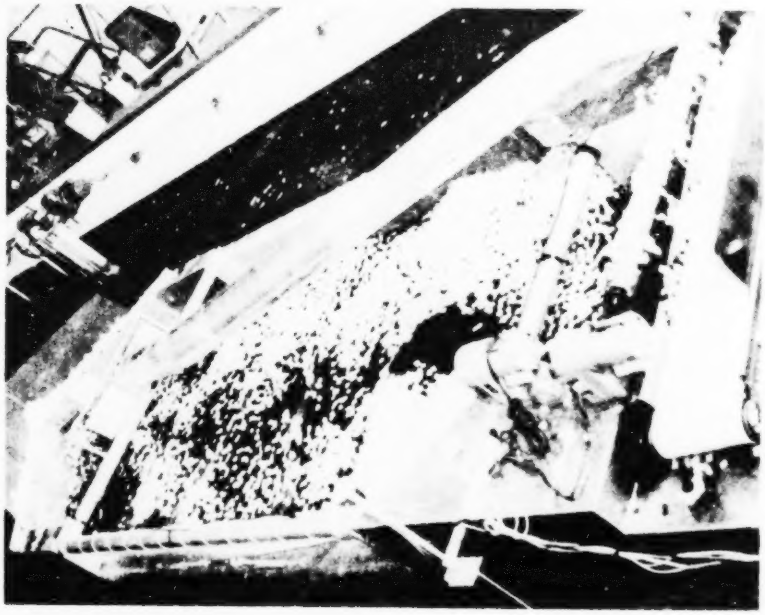


Harvesting and Transfer Conveyor

FIGURE 67 - RECOVERY PLATFORM OPERATING IN SEA STATE
1 AT 3 ft/sec



Recovery Platform Being Towed



Recovery Platform Being Pushed

FIGURE 68 - RECOVERY PLATFORM OPERATING IN SEA STATE 3 AT 3 ft/sec

it is possible to maintain a continuous sorbent broadcasting and recovery process without constant adjustments by the operating crew.

2. The sorbent broadcasting and recovery operation is not degraded by waves up to a low sea state 3. The tests showed that the broadcasting and recovery processes are not greatly effected by waves up to the height tested. The freeboard and draft of the platform are sufficient to prevent sorbent loss due to waves breaking over or washing under the aft pontoons and harvesting conveyor. The relative motion probe showed that relative motions in short waves do not greatly exceed the wave height and in moderate and long waves, the platform contours the waves with only small relative motions. This is illustrated by relative motion data obtained in regular waves which are presented in Figure 69. These data show that relative motions will be small in wavelengths equal to or greater than the platform overall length.

3. The broadcasting nozzle developed in Task 2 will provide a uniform distribution of sorbent over the width of the recovery platform. These tests further confirmed the validity of the broadcasting nozzle concept developed in Task 2. The quality of the distribution pattern across the width of the recovery platform is illustrated in Figures 66 through 68.

4. The sorbent material can be recovered by a harvesting conveyor half the overall sorbent pattern width. During the tests, there were no indications that the sorbent material would form a bridge or plug across the inlet to the harvesting conveyor. In waves, the inboard sides of the aft pontoons reflect waves back to the center of the recovery bay. These reflected waves tend to locally herd the sorbent material to the center of the harvesting conveyor. Thus, in waves, there is no chance that the sorbent material could form a plug across the inlet to the harvesting conveyor.

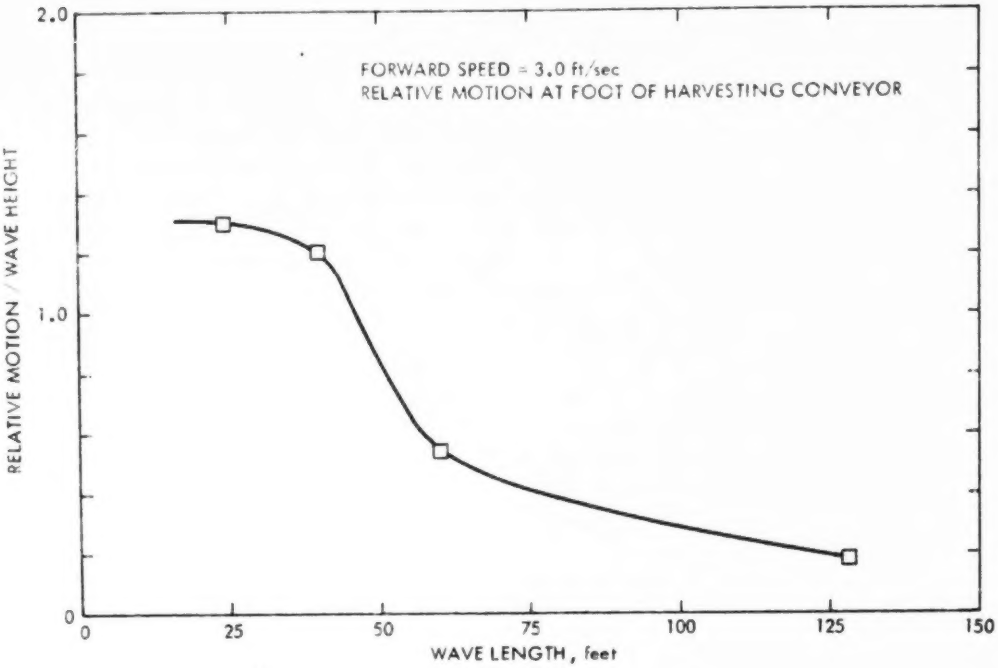


FIGURE 69 - SORBENT RECOVERY PLATFORM RELATIVE MOTION IN REGULAR WAVES

Results

The important results of this developmental program can be summarized as follows:

1. The test program showed that a continuous sorbent broadcasting and recovery operation with a uniform stable distribution of sorbent material can be achieved.

2. The sorbent broadcasting and recovery operation was not degraded by waves up to a low sea state 3 and forward speeds up to 6 ft/sec.

3. The broadcasting nozzle concept developed in Task 2 provided a uniform transverse distribution of sorbent material.

4. The sorbent material did not show any tendency to plug the inlet to the harvesting conveyor.

5. The recovery platform can be towed up to a speed of 9.5 knots in the deployment condition.

6. The recovery platform is directionally stable under tow.

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